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REVIEW OF ENGINEERING PROGRESS ABROAD

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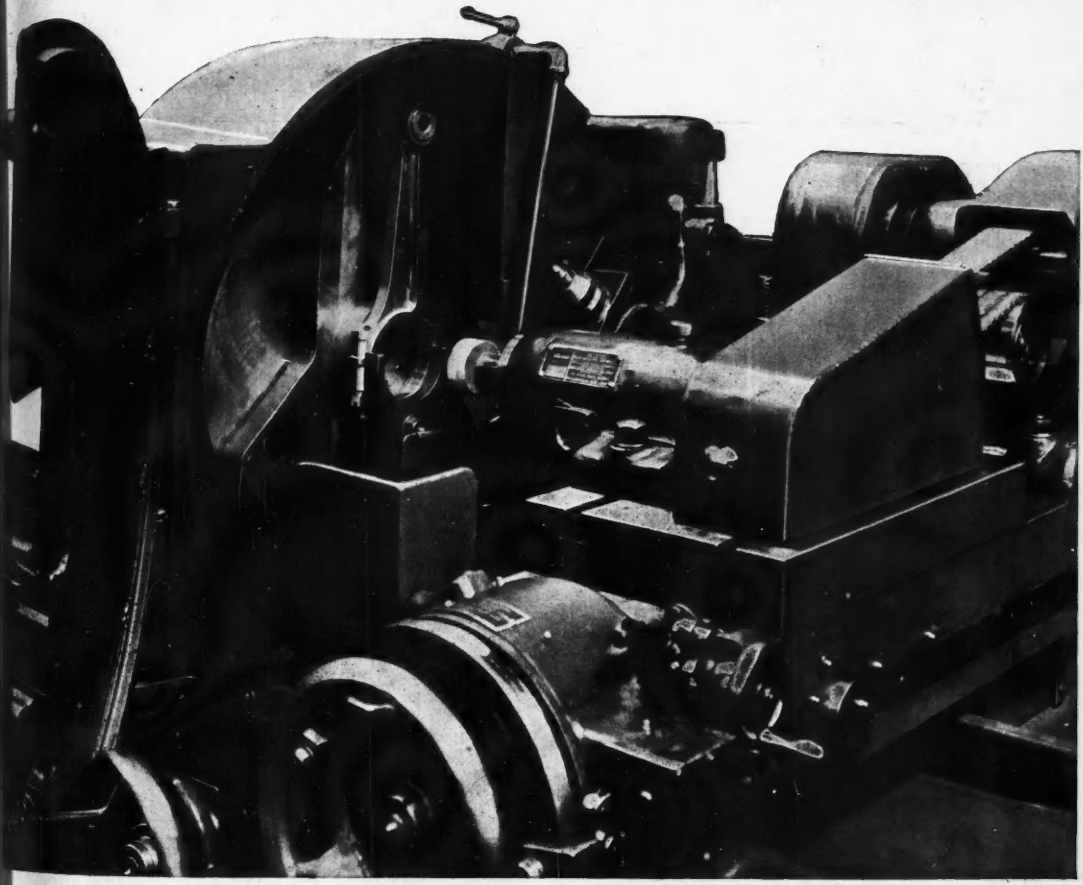

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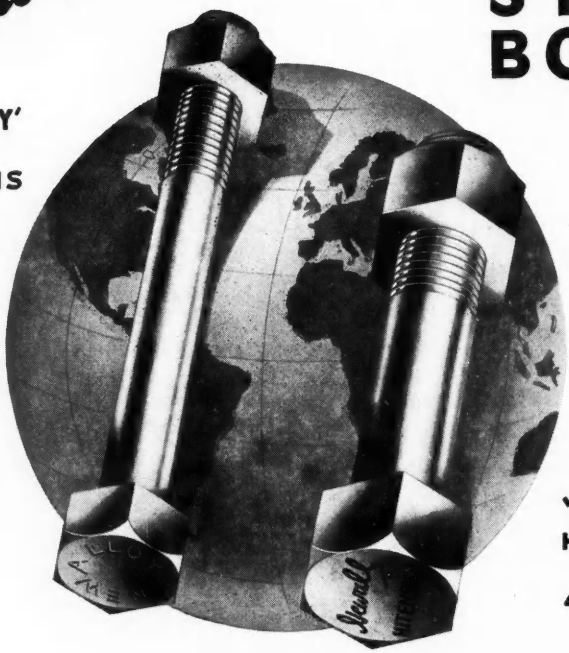

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May the combined efforts of us all bring the War to a victorious end in 1943.

POWER PLANT PROBLEMS

Summary of Discussion of Ten Questions by A. S. M.E. Power Division. (From *Mechanical Engineering*, Vol. 64 No. 9, September 1942, pp. 669-672).

A ROUND table discussion of power plant problems of current interest by power plant operators, engineers and equipment manufacturers, under the auspices of the A.S.M.E. Power Division, was a feature of the Semi-Annual Meeting of the A.S.M.E. held in June, 1942. J. C. Hobbs, vice-president in charge of manufacturing, Diamond Alkali Co., was recorder and prepared the summary of the discussion, which is reported in what follows.

1. *What can be done to improve cleanliness of boiler surfaces, thereby lengthening the periods between shut-downs now required in most cases for hand cleaning?*

Chemical water treatment was recommended. Cleaning practice varies from turbining each time a boiler is out of service, to intervals of a number of years. Cleaning of the upper portion of the furnace walls materially improves the condition of the boiler tubes proper by lowering the temperature of the gases entering the tube bank. Fineness of pulverization and the amount of excess air are also related to external cleanliness of tubes. Access doors for hand cleaning should be provided wherever necessary. Oil refinery sludge sometimes carries high percentages of moisture and salt, and the latter causes serious furnace refractory fluxing and plugging of the last tube bank. The necessity of reducing the number of coarse particles to a minimum in pulverized-coal furnaces as compared with absolute fineness was emphasized. Crushed coal and pulverized coal cannot be burned successfully in the same furnace.

2. *How can availability of boiler units be increased by shortening the outage time now required for internal tube cleaning?*

Boilers fired with natural gas or with oil present a simpler problem than coal fired units requiring both external and internal cleaning. Filtration and recirculation of boiler water under pressure through anthracite was suggested. Silica represents a special problem. Control of pH is desirable. Sample tube turbining is used by one company to determine whether the boiler needs complete cleaning. Some high pressure boilers have been operating without internal cleaning. Others are cleaned until a history is obtained. Water conditioning is a separate problem for each boiler plant, and until treatment is under control, turbining is necessary. Corrosion must also be watched, particularly to prevent nodule oxidation. Cleaning with acid may or may not eliminate the nodule pitting as well as turbining.

Dow Chemical was reported as having a separate acid-cleaning department for oil wells and boilers. The technique depends upon information obtained by taking a sample of scale and testing it for solubility. The object of using acid is to save time and labour cost. Acid cleaning is very effective in some cases.

3. *What are the possibilities of external tube corrosion or wasting occuring on furnace wall tubes of boiler units not equipped with slag-tap furnace construction? Has increase in total air at the furnace wall eliminated further attack where this type of corrosion has occurred?*

The discussion of this question was opened by the following statement: It is believed that external tube corrosion, or wasting, can occur on furnace wall tubes of boiler units having furnaces arranged for dry-ash removal, if flame or fuel impingement is sufficiently severe. Quite a number of furnace installations have been inspected for this tube wastage condition, but to date no evidence of this condition has been found. On one installation, equipped with radiant superheater in the side wall, an attack of the chrome-vanadium tubes, then used, occurred about ten years ago. The cause was found to be severe flame impingement on the region attacked, and elimination of this flame impingment brought about a correction of the trouble. Increasing the total air at the furnace wall is probably equivalent to elimination of flame or fuel impingement. It is believed that any corrective measure that provides oxygen in the region where the attack is taking place should eliminate this type of attack.

External tube wastage has proved to be a serious problem in a number of slag-tap installations. There is unanimous opinion that the trouble is definitely related to zones of furnace walls covered with molten slag where the atmosphere is deficient in oxygen as indicated by the presence of an appreciable percentage of CO. The present cure has been to introduce additional air either through spaces between tubes of the wall or on the boundary lines of burners, so as to keep an appreciable oxygen content in gases adjacent to the walls. Both

chrome paint and spray metalising have been tried without notable success. Iron sulphide was at first thought to be a prime factor, but evidence now indicates that the active wastage is usually in the presence of some alkali-sulphur compounds which analyse largely sodium and potassium sulphate after the boiler has cooled down.

4. *What amounts of ammonia can be tolerated in our steam and water circuits before troubles can be expected with desincification of condenser and heater tubes and possible acceleration of internal boiler surfaces the results of metallic copper deposits ?*

One school of thought indicates that copper and boiler tube corrosion might appear to be related because some copper has been found in corrosion barnacle pits. Another school believes that copper has not been responsible for the corrosion. Copper is soluble in ammonia and might be taken up from alloy parts and deposited later in the boiler tubes. Copper has also been found in intercrystalline faces of boiler metal. There was a distinct difference of opinion—some of the discussers felt that if copper were not the cause, it was closely related to it. Another case of metal failure near copper gaskets was labelled by one discusser as being related to the copper but by another as being caustic embrittlement.

5. *What is safe practice to follow with respect to turbine inspection ? Can present schedules of overhaul be lengthened ?*

The general practice which has been suggested by the turbine manufacturers and agreed to by most of the insurance companies, and generally followed by the majority of turbine operators, is to inspect a new turbine unit in the period between six months to a year after it is initially placed in service, then to carry out subsequent inspections after approximately 10,000 hours of operation. This would, of course, require inspection under normal circumstances every two to five years, depending upon the operation of the machine.

On older turbines it has been the general experience that inspections of this frequency are good insurance against unscheduled outages because potential difficulties can generally be anticipated and repair material accumulated in advance.

On more recent machines, on which bucket difficulties have been to a very great extent reduced, we find that the period from initial installation to the first inspection is the critical one because then difficulties due to foreign material or deposits, or those originating from design modifications, are apt to show up, and after that period it may be safe to extend the time between inspections.

Probably all turbine manufacturers are making available to the operators an important tool in this connection. This is the curves of anticipated stage pressures against load which, if carefully checked by the operators with the actual stage pressures following initial operation and corrected thereto and from then on checked at frequent intervals against the actual stage pressures existing in the turbine under operating conditions, will permit the internal conditions of the machine to be watched very carefully. That is, deposits or damage due to the entrance of foreign material, or damage due to bucket difficulties, are immediately apparent ; and it would seem reasonable to assume that as long as such data which have been taken indicate the machine to be in first-class condition, inspections could be intelligently and safely deferred.

The turbine manufacturers appeared to be in agreement in recommending an interior inspection of all new turbines within six months after installation, a year to be the maximum limit because in this period the major difficulties ascribed to foreign material, plant conditions, turbine design, defects, and other things will be evident.

6. *What methods are available to prevent the loss in turbine capacity caused by the accumulation of soluble and insoluble deposits on turbine blades, buckets, and nozzle partitions ?*

The turbine manufacturers took the position that clean steam is the answer, their definition of clean being better than the purity now being supplied. They claim that the boiler manufacturers and operators do not realize how seriously the steam cleanliness affects the outage and capacity of the turbine because with the passage of millions of pounds of steam through the turbine, some accumulation will occur. Steam deposits may be found in various parts of the turbine depending upon the character of the material being deposited, whether it is soluble, or insoluble, and the steam conditions and the operating conditions of the turbine and boiler. A very important variable appears to be the character of the ground water in the place where the plant is located, even though evaporated make-up is used. Soluble deposits generally form at earlier stages of the turbine, and insoluble deposits in the middle stages. Both kinds of deposits plug up the turbine passageways, increase the pressure drops across certain stages, and upset the energy distribution in the turbine, thus increasing the energy on certain stages and taking off others, with resultant loss in efficiency, and seriously decreasing the hydrodynamic efficiency of the steam-path elements themselves.

Although washing may remove deposits, it must be carried out extremely carefully to prevent damage to the turbine from differential temperature changes, takes a considerable period of time, thus requiring appreciable outage, and for obvious reasons should not be done more frequently than necessary. On the other hand, if not carried out frequently enough the reduction in capacity and efficiency may become appreciable before washing. The only certain method of removing insoluble deposits is to open the turbine and clean the steam passages with an air blast containing fly ash or other equivalent material. There is some evidence, based on some German research work by a Dr. Spillner, that this problem is intensified by the trend toward higher pressures due to the increasing solubility of salts in the high pressure steam in the boiler drum, and that it may not be due, as previously thought, to the mechanical carrying over of entrained moisture in the steam with its high concentration of boiler salts from the boiler drum. These tests would indicate that much might be accomplished by thoroughly washing the steam with the incoming feed water between the boiler drum and the entrance to the superheater as has been tried with some success in a number of installations.

One important fact stands out, and that is that many plants have had serious troubles which have subsequently been rectified, and that many plants are now operating, both low-pressure and relatively high-pressure plants, with no evidence of turbine deposits. This would, therefore, make it appear hopeful that this problem can be eliminated.

7. *What are the possibilities of removing present "bottlenecks" in existing power plants thereby increasing the maximum capacity ?*

Attention was called to losses due to steam line radiation, to the falling off of boiler feed-water heater performance by 20 or 30°F. to the co-ordination of operations so as to reduce peaks, amd to a number of other opportunities which had been found in the steel industry. Bottlenecks have been opened by attention to coal pulverizer performance, stoker operation, induced

draft-fan vortexes, steam carry-over, furnace temperature, tube cleaning, circuit-breaker design, and turbo-generator operation on temperature rating instead on name plate rating. Another discusser illustrated the elimination of one bottleneck after another in a manner which gradually increased the capacity of the whole plant.

8. *What is the experience in connection with turbine lubrication as to temperature, length of life, etc.?*

In many recent turbines trouble has been found upon first putting the unit in service on account of very severe rusting on the steel parts throughout the oiling system, namely, oil tank, oil lines, bearing pedestrals, etc., although the bulk of the trouble has occurred in the oil tank. According to our lubrication specialists, the trouble was largely due to change in method and degree of refining of turbine oil to obtain what were considered important qualities, namely, absence of sludging and low steam emulsion numbers. The older type of turbine oils, which had higher steam emulsion numbers and which sludged more easily, contained natural rust inhibitors in a sufficient amount to prevent rusting. But these old types of oils were extremely short lived. It should be possible to retain the more highly refined oils and, through the use of corrosion inhibiting aditive agents, remove the corrosion hazard, while at the same time retaining the desirable characteristics of the newer oils.

Most of the troubles seem to occur in the early period of the turbine's operation when the operating group or the turbine erectors had frequently not been able to reduce to a minimum the entrance of water into the oiling system. There is evidence, however, that if the turbine oiling system can be protected for this interval by painting the pipes and tank walls, the oil may develop natural rust inhibitors in sufficient quantity so that thereafter the oil will wet the surfaces and thus prevent the development of the more severe types of corrosion. This matter is being very carefully attended to, but is handicapped at the moment because of difficulty in obtaining some of the materials in the type of rust-preventing, oil-resistant paint which has had the greatest period of general service.

In the meantime, the specific oil company involved should be consulted by the new turbine owners and asked for a guarantee that the oil used will not cause this corrosion during the initial starting of the turbine. And if such a guarantee cannot be given, it is recommended that the new turbine should be started on old oil or a large percentage of old oil.

9. *What can be done to improve burners, particularly for mixed fuel? If sulphur is a factor, one quarter of one per cent. may be enough to cause trouble; in few cases can sulphur be reduced to a figure below that amount.*

One case was reported in which a tangential system, originally having 4 ft. circle, was changed so that rotation at the bottom was in a 1 ft. circle, counter clockwise, and at the top, in a 1 ft. circle clockwise. Errosion trouble on the three walls was eliminated and the third greatly reduced by this change involving a better distribution of secondary air. Burning of mixed fuels is a very complicated problem. The distribution of air under stokers is very important and one plant found that it was very desirable to sub-divide the wind box.

10. *What substitution can be made for essential materials required for construction and maintenance of power plant?*

This subject brought only one response, which related to a case of using asbestos roofing paper on low-pressure equipment joints as a substitute rubber gasket.

INCREASE IN OUTPUT BY AUTOMATIC OPERATION OF MACHINE TOOLS

By Dr.-Ing. H. H. Finkelnburg. (From *Die Werkzeugmaschine*, Vol. 6, No. 11, June, 1942, pp. 321-327).

Automatic operation of machine tools is not only achieved by controlling each machining operation, but also by controlling automatically the supply of raw material in the machine. Should this not be carried out then an operator is necessary to stand by and re-load the machine after the completion of each cycle of operations constituting those necessary to complete the machining of the finished article. This is only practical if the time taken to complete the cycle of operation is very long and when the work of feeding the machines fits in with the general framework of machine minding. The feeding or re-loading of the machine should be carried out in the shortest possible time and without the assistance of a machine minder. By taking this precaution it will be found that the output of the machine is increased. It is, therefore, necessary when considering automatic machinery to give special consideration to the problem of feeding the machine with material.

The type of equipment used in feeding the machine with material is governed by the kind of material to be machined, the cutting speeds and the requirements necessary in locating the raw material in the machine. It can be pointed out that the location problem is especially difficult when the cross section of the material is not symmetrical.

If the material to be fed to the machine is in rod, tubular or bar form no difficulty is experienced in automatic feeding, Such sections of material are used in all kinds of automatics, as well as in mechanical saws, parting-off lathes, thread cutting machines, etc. If the raw material remains stationery throughout the cutting or machining operation, all that is required to move the material forward in the machine when re-loading is a chain attached to the free end of the material. By attaching suitable weights to the chain the material will be forced forward as soon as the chuck is opened. This arrangement is shown in Fig. 1. When the end of the bar makes contact with a stop, further forward movement of the bar is prevented and the chuck is closed. An arrangement of this type

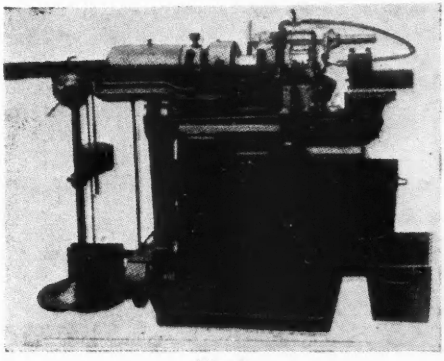


Fig. 1

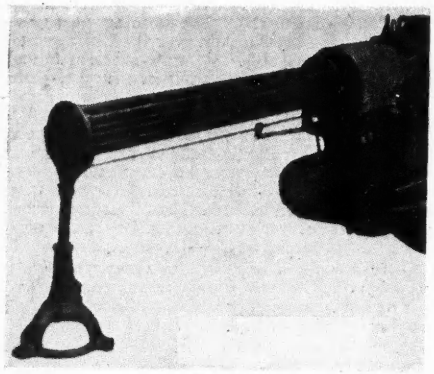


Fig. 2

cannot be used, however, for high-speed, high-duty machines, requiring a frequent re-loading of the material. In such cases, it is usual to employ a feed collet arranged in the hollow mandrel of the machine. The feed collet is mounted directly behind the chuck so that it is possible to use up all the bar, excepting a small end piece. The feed equipment is actuated from the end of the hollow mandrel or spindle. As long as the chuck holds the material tightly, the feed collet will slide back over the material. During the interval of re-loading the machine, the chuck is open, and the forward moving collet carries the material forward. The collet is sprung around the material, with a force so arranged that the material can be carried forward with the collet and then made to slide backwards over the material.

As soon as a bar of the material has been used-up a new bar will be inserted in the machine and during the change the machine will be shut down. To offset the loss in time, thereby incurred, it is usual to use very long bars of material in order to reduce the frequency of re-loading the machine with material. The free end of the material which hangs out of the machine is carried in a feeding rod as shown in Fig. 2. The dimensions of the feed tube are chosen to suit the size and section of the material being worked in order to

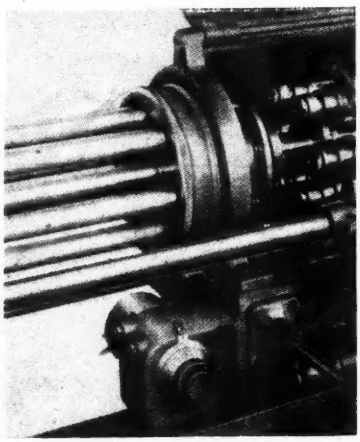


Fig. 3

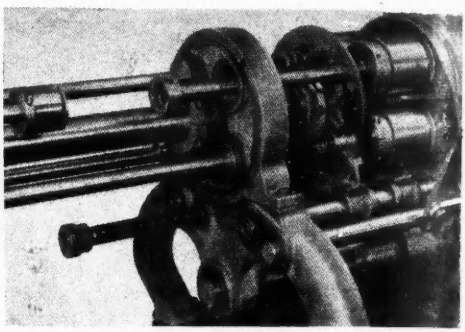


Fig. 4

ensure steady running. In the same way, a dual feed bar consisting of an outer feed tube and inner feed tube mounted in ball bearings, has proved advantageous. The inner tube carries the material and rotates with it. Similarly feed tubes have been used stuffed with special material in order to reduce noise.

To facilitate the re-loading of the machine with fresh bars of material, many types of re-loading devices have been developed. The numbers of parts which can be cut off a given bar is governed by the length of the bar and by the overall length of the finished part. This number can be recorded on a special counter or meter attached to the machine, shown in Fig. 3, which is a six spindle automatic. As soon as the material has been used to the extent that the free end no longer rests in the feed tube, but rests only in the hollow mandrel of the automatic, a lamp operated by the counter device is illuminated. The feed tube is then uncoupled from the machine and re-loaded, during the time that the end piece of the bar is being machined.

In order that the individual feeding bars of the multi-spindle automatics carrying heavy material can be withdrawn independently and easily, the feeding bar is not built rigidly to the automatic nor is it taken out completely. Each feeding bar is withdrawn and through

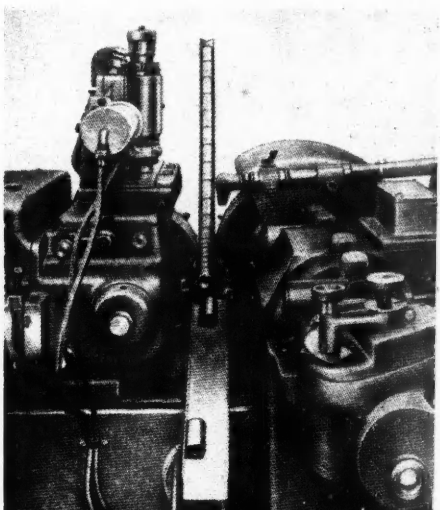


Fig. 5

the resulting opening in the revolving plate, the feed tube or rod can be pulled out as shown in Fig. 4. This simplifies the work of feeding the material in the lathe.

When the material being fed to the machine is not in bar form, but is in the form of individual castings or pieces, the equipment used for feeding the machine is very different from that used to feed machines with bar material. The method in which castings, forgings, stampings and pressings are fed into the machine depends upon their shape. Little difficulty is experienced with the feeding of parts which have been previously turned, having both ends of similar shape. In a case like this it does not matter which end receives the subsequent machining operation and, therefore, which end is fed first to the machine.

Fig. 5 shows a suitable hopper or feeding magazine used for feeding bored cylindrical rollers into a centreless grinder for the finish grinding operation. As the roller

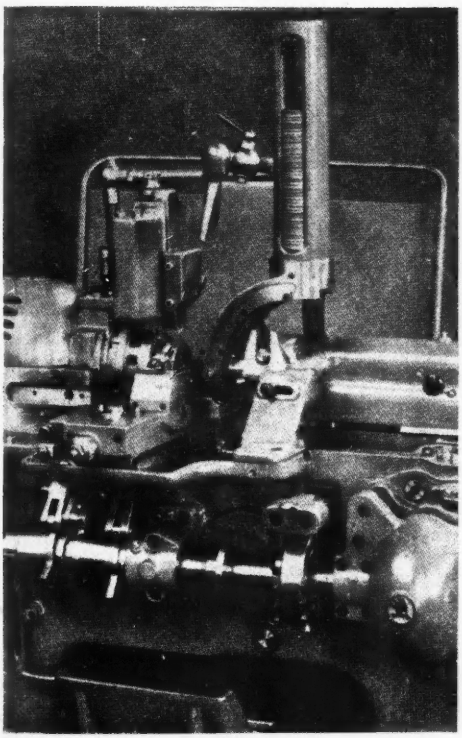


Fig. 6

blanks are sufficiently long and the tendency for them to tilt is small, the hopper shute can be a simple channel, suitably inclined so that the weight of the material is sufficient to overcome friction. A forward movement of the rollers to the grinding wheel is thus ensured. The hopper length depends upon the possibilities of location and also upon the cutting speeds used in order that a too frequent re-filling of the hoppers can be prevented. The shorter the time of operation, the more frequent will it be necessary to re-load the hopper.

If raw materials are to be machined having large diameters relative to their length, i.e., disc shaped components, so that there is a tendency for them to tilt, a 'closed' type hopper as shown in Fig. 6 is desirable in place of the 'open' type. The discs are placed into

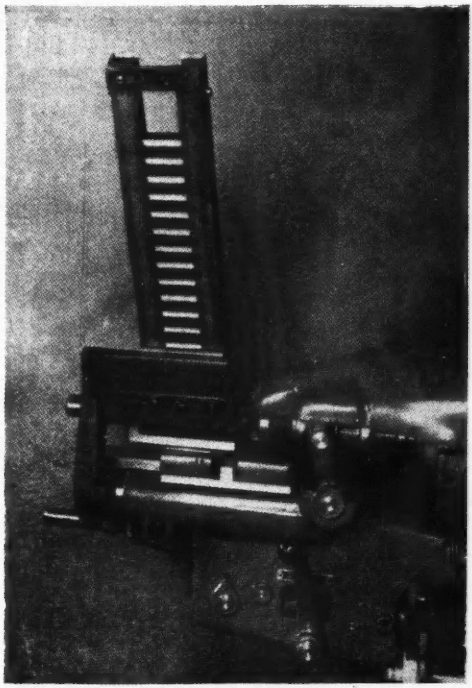


Fig. 7

the feeding magazine or hopper and lie vertically above one another as shown in the figure, which is the arrangement adopted for a single spindle auotmatic. The curved feed shute is noteworthy for after the completion

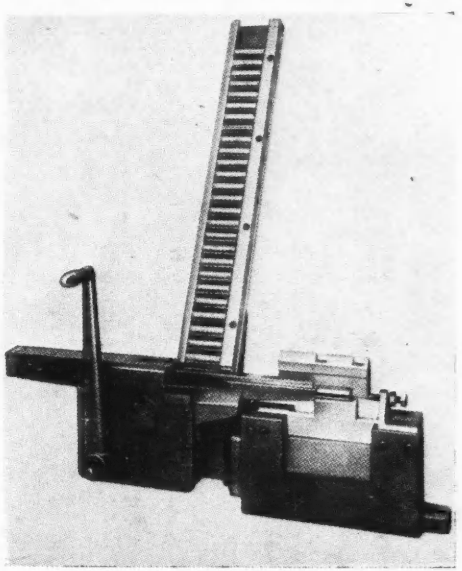


Fig. 8

of the machinery operation, the next disc is withdrawn from the hopper and, after tilting, is conveyed to the chuck.

Roller shaped components can also be arranged in a hopper with their axis in horizontal positions so that they roll downwards towards the tool as shown in Fig. 7, which is the hopper arrangement for an automatic machine. When the operations on the blank are completed, the next blank is removed from the hopper and conveyed so that its axis and that of the hollow mandrel of the lathe are in the same plane. A finger actuated at the back of the blank pushes the roller blank into the hollow mandrel so that all the blanks in front of it are moved forward. In this way the completed component is simultaneously ejected out of the chuck and the foremost blank is then clamped into position for machining.

A special feeding device used for a centreless circular grinding machine is shown in Fig. 8. The actuation of the feeding of material can be done by hand or automatically. Here again, the lowest blank is pushed forward into position by the actuation of a finger.

All these hoppers and feeding devices do not hinder machining operations. It is a different matter when the blanks are fed to the machine from the chuck end as shown in the case of an automatic in Fig. 9, rather than through the tail end of the hollow mandrel. The feeding device must be arranged, therefore, so that first of all a radial path is performed in front of the chuck before the blank is pushed into the chuck. Such feeding devices or hoppers are accommodated on the cross slide of the machine as is shown in Fig. 9, where the hopper and under it, the conveyer with a rack and pinion is situated. The pinion is mounted on the moving cross slide, the rack is mounted on the rigid hopper which travels twice the radial distance of the cross slide.

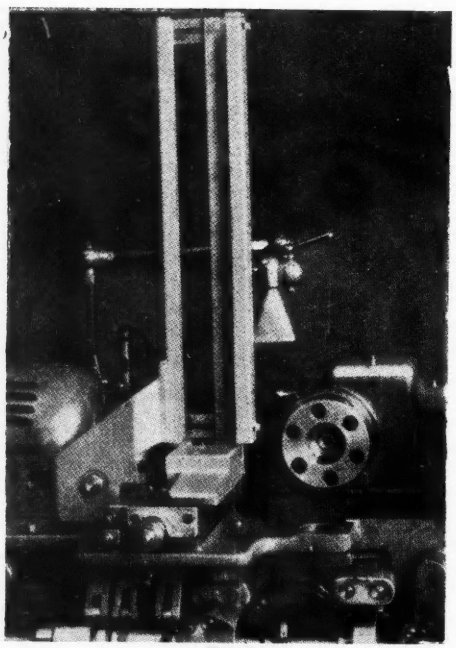


Fig. 9

It is important that with all feed devices that the movement forward of one blank at a time is assured and that it occurs without jamming. The conveyer is therefore so arranged to receive only one blank and then with further movement close the mouth of the hopper. Such a conveyer or receiver is shown in Fig. 10. A practical conveyer can be designed in the form of a circular hollow cylinder as shown in Fig. 11. The conveyer closes the hopper chute and only in one position is it possible for a blank to roll through a port into the conveyer.

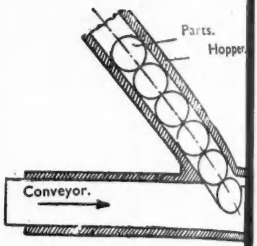


Fig. 10

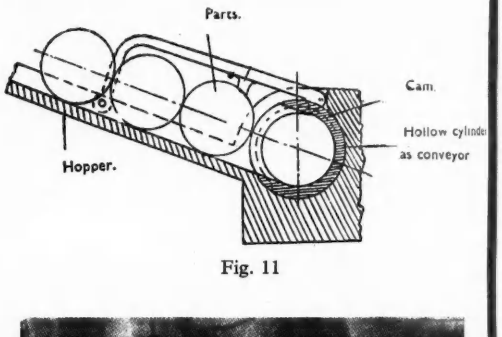


Fig. 11

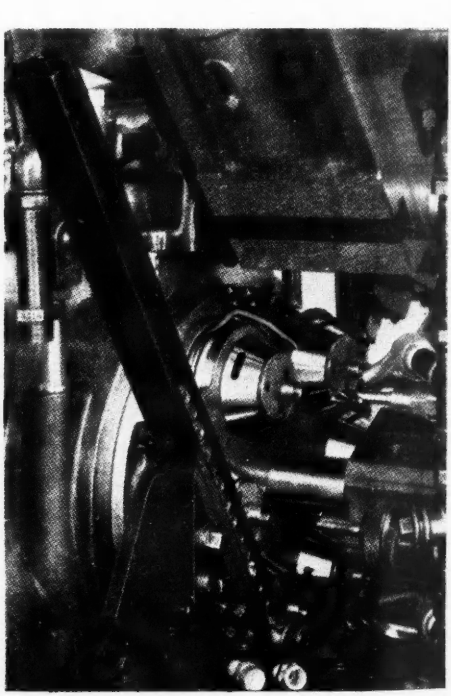


Fig. 12

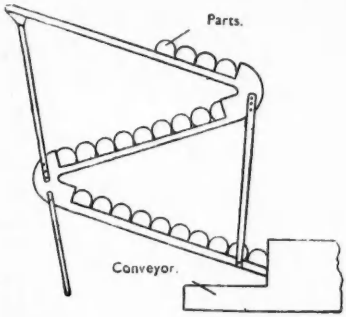


Fig. 13

Hoppers can be arranged to accommodate blanks which, due to their outside cross section, cannot roll. In such cases the chute must be designed to suit the shape of the blank and steep enough to allow the blank to slide when re-loading is carried out. Such a hopper is shown in Fig. 12 and is used in a multi-spindle automatic for cutting material of hexicon section. An arrangement for increasing the length of the hopper for parts requiring short times of operation is shown in Fig. 13. In arrangement of this sort it is important to give special attention to the design of that part of the hopper which changes the direction of the blank during its travel downwards. Another type of space saving hopper is the spiral type accommodating a large number of blanks, shown in Fig. 14.

It is essential that the size of the hopper should be large enough to allow at least one hour operation before it becomes necessary to re-load the hopper with fresh blanks. If, as for example, a blank has an outside diameter of 50 mm. and the time taken in performing the machining operations is 36 sec. the number of parts which can be machined hourly is $3{,}600/36 = 100$ pieces. Hence, the hopper should be designed to accommodate 100 blanks, requiring a length of hopper of 5,000 mm. If a straight chute can have only a length of maximum 1.5 to 2 meter, it corresponds to a loading capacity of the order of only 3 to 4 spiral turns. With a spiral hopper of only 300 mm. pitch circle diameter it is possible to accommodate $300.11/60 = 19$ parts or blanks on one spiral circle. It follows therefore, that 6 spirals or turns would be necessary. The height of the hopper would be only 700 to 800 mm., hence very small space is occupied.

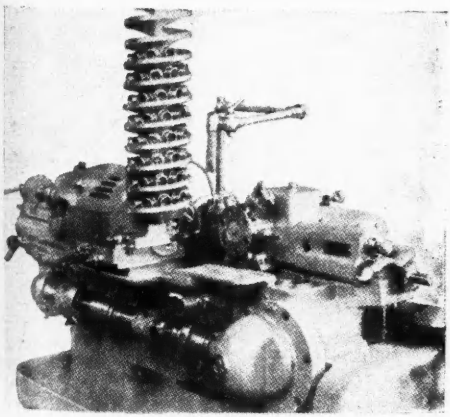


Fig. 14

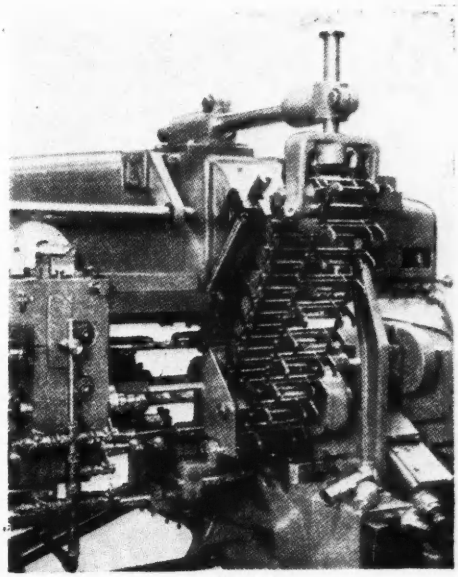


Fig. 15

There are a great number of components which cannot roll or slide towards the chuck because they cannot be located tightly against one another. They are mostly parts having one-sided projections or other unsymmetrical shapes. So as not to forgo the advantages of automatic feeding of such difficult cases, the blanks are tightly deposited in a moving hopper and through the motion of the hopper the parts are moved or fed to the machining position. There are many types of moving hoppers. Fig. 15 shows a chain type hopper which moves forward in stages, carrying in each of its links a blank for machining. Horizontally arranged conveyer belts containing pockets for carrying the blanks and rotating hopper tables, also containing suitable pockets for the blanks, have proved useful.

When the time taken to perform the machining operation can be counted in seconds or fractions of a second, the re-loading of the hopper takes up so much

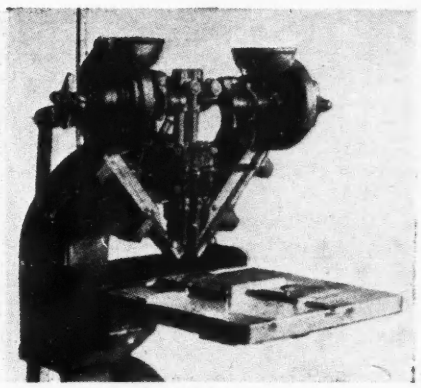


Fig. 16

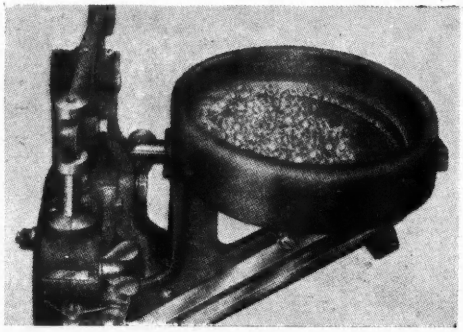


Fig. 17

time that a man is fully occupied in keeping pace with the machine. As an example of this Fig. 16 shows the arrangement used, in an automatic riveter, which is used for riveting leather parts with two rivets simultaneously. The feeding of the small rivets in the two inclined hopper chutes by hand cannot be carried out economically. For this reason a funnel type filler has been designed so that the rivets can be tipped into them. Special mechanism ensures that the rivets are arranged in their right position before entering the hopper chute.

A similar arrangement is shown in Fig. 17 and 18. The slowly rotating base of the pan or drum moves the blanks to its outer circumference where they are led into the hopper which leads helically into the hopper chute. Badly arranged, or too many parts at one time cannot be led into the chute but are returned to the pan. By this method it is even possible to exclude any scrap blanks from entering the hopper. Thus a preliminary inspection of the parts can be omitted.

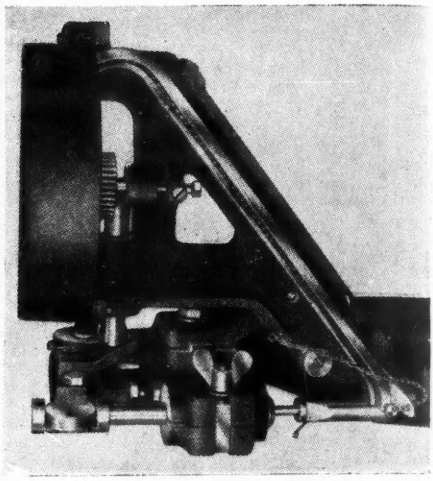


Fig. 18

MODERN AUTOMATIC SAWING MACHINE WITH HYDRAULIC GEAR

(From *Werkstatt und Betrieb*, Vol. 75, 1942, No. 5, pp. 108).

To meet the general tendency to highly specialized production the automatic sawing machine as described below, has been designed. It is being manufactured in two sizes.[1]

The machines are intended for cutting bars of various material and cross section, ranging from the hardest steel bars to thin walled tubes of light alloys or plastics. The diameter of the material to be cut is limited to 60 mms.

The bar is fed into the machine at *a* (Fig. 1) and advanced by the length of the piece to be cut off. The bar is then seized by a vice *b*, and held tightly while the saw carried by the slide, *c*, approaches the bar. When the sawing operation is finished sawing blade and slide return to their initial position. The sawing blade is stopped, the vice releases the bar which is pushed forward again. This cycle of operations is automatically repeated until the whole bar is cut up to the required lengths. The operator, usually attending a number of machines simultaneously, is warned by a

(1) Manufacturer: Franz Irmischer, Maschinenfabrik und Eisengiesserei, Saalfeld/Saale.

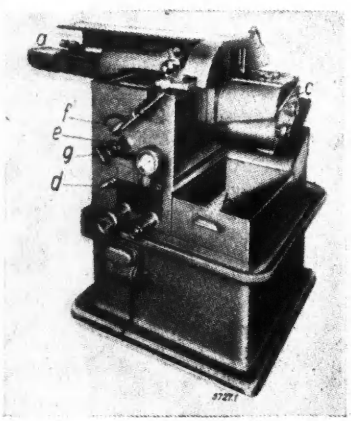


Fig. 1

Automatic sawing machine with hydraulic gear, for materials up to 60 mm. dia. Range of cutting speed 12 to 250 m/min. adjustable by change gears.
(a) Guide for feeding the bar into the machine.
(b) Vice.
(c) Blade slide with gearing for changing the cutting speed.
(d) Throttle valve used when cutting tubes, or bars with special section.
(e) Handle to adjust cross feed of saw blade.
(f) Lever for automatic cutting of single pieces. (g) Lever to stop the automatic feed of bar. (h) Receiving box.

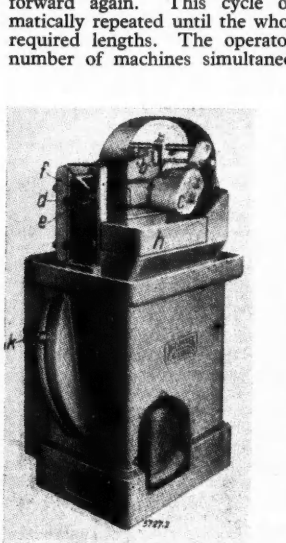


Fig. 2

Automatic sawing machine with hydraulic gear for materials up to 33 mm. dia. Cutting speed adjustable from 8 to 330 m/min. by (1) changing the gears, and (2) by regulating the hydraulic gear, for continuous change of the cutting speed.
(b) Vice.
(c) Blade slide with gearing for changing the cutting speed.
(d) Throttle valve used when cutting tubes, bars with special section, etc.
(e) Handle to adjust cross feed of saw blade.
(f) Lever for non-automatic sawing. (h) Receiving box. (k) Lever for continuous adjustment of speed.

bell. The number of pieces cut-off is automatically registered.

The feeding mechanism of the bar as well as the vice and the cross feed mechanism of the slide are hydraulically operated. The pressure tubes are of steel to withstand the working pressure of about 25 atm.

Serving the machine involves only the insertion of the bars. The cutting speed can be easily adjusted according to the material. This gives the machine a great versatility and makes its use economical even for small factories where the serial cutting of one particular material is small. In order to keep down the time of preparation, which becomes an important factor if the material is frequently changed, the cutting speed can be simply adjusted by a handle. This handle is connected to the so-called "variator" which can change the cutting speed from a basic speed up to a speed of 6 times as high. The change of speed is stepless.

To saw various materials it becomes necessary to change not only the cutting speed but the cross feed of the saw blade as well. The button, *e*, serves this purpose and the cross feed is adjusted in the simplest way. Special vice jaws can be used for special duties, e.g., for cutting delicate thin walled tubes or bars not of standard section.

UP-TO-DATE SUMMARY OF QUESTION OF DETONATION*

By Dr.-Ing. Habil. Fritz Dreyhaupt. (From *ATZ Automobiltechnische Zeitschrift*, Vol. 44, No. 21, November 10th, 1941, pp. 521-533).

I.

1. The Phenomenon of Knocking.

If the compression ratio in an Otto engine is gradually increased, Fig. 1., then at a certain c.r. value knocking combustion starts and the following observation can be made :

(i) The rate of power increase with increasing c.r. value is reduced.

(ii) A "knocking" or "pinking" noise becomes audible.

(iii) The specific fuel consumption increases.

(iv) The exhaust gas temperature is raised and may score the exhaust valves.

(v) The whole of the engine becomes strongly overheated.

(vi) If knocking combustion is permitted to persist for a longer period, serious damage might occur to the piston, piston rings, cylinder liner and main shaft bearings. The appearance of the damaged parts indicates that the damage was due to thermal and mechanical effects.

The power of the highest useful compression ratio (H.U.C.R.) is known to be dependent upon the quality of fuel. The three types of hydrocarbons found in volatile fuels, namely aromatics, naphtenes and paraffins, take this order of merit in regard to knocking. The ante-knock value of the fuel increases with the chemical stability, decreases with the size of molecules, and depends also upon the presence of a certain group of atoms (alcolhol) in the chain of molecules. So far, however, no universally valid relationship between chemical composition and tendency to knocking could be established. It must be also remembered that the Octane scale is an artificial parameter of fuel quality since size, speed, combustion chamber design and many other technical details of the engine affect not only the numerical value of the Octane number but in some cases even the order of merit of the fuels. Thus hot engine walls and air pockets promote knocking effectively, especially if these are far distant from where ignition starts. To a lesser extent the same applies to a longish combustion chamber design. On the other hand a compact, almost spherical or semi-spherical combustion chamber with centrally arranged sparking plugs, that is with a short route for the flame front, reduces the danger of knocking and consequently the H.U.C.R. value can be raised.

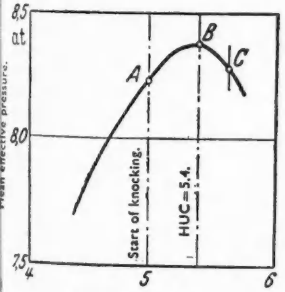


Fig. 1

2. Thermal Condition of "End Gas."

Already very early investigations of the problem of knocking have established the paramount importance of the charge which burns last in a cylinder (in the rest of this article referred to as "end gas") and the factors controlling it's thermal condition.

The chemical reactions, brought about by normal combustion and progressing in the cylinder from the primary point of ignition (i.e. sparking plug), are responsible for local heating along the flame front and volumetric changes of considerable magnitude. Consequently, strong pressure waves are originating from the flame front compressing the still unburnt charge ahead of the flame front and the products of combustion behind it. These pressure waves increase the temperature of the unburnt charge according to adiabatic compression. The conditions are illustrated in Fig. 3 for the case of a spherical combustion chamber, of radius $r = R_o$, according to Mach's theory.

(Note : the compression effect of combustion only is considered, neglecting the compression due to piston movement). In Fig. 3, for simplicity's sake it was assumed that the pressure is equalized in the whole of the combustion chamber very rapidly (at a velocity of sound), during which period the temperature equalization (by transmission, conviction, diffusion) in the

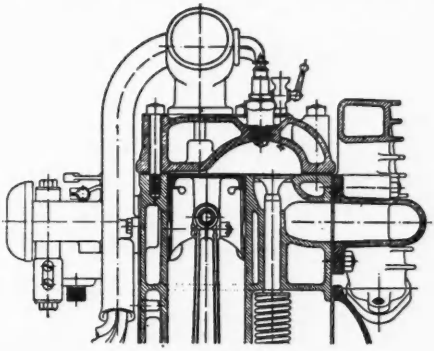


Fig. 2

* In the English technical literature "Detonation" is the name of a well known engine phenomenon corresponding to the German "Klopfen" or knocking. Unfortunately Detonation has also a meaning in chemical terminology : it is the name of a very rapid combustion accompanied by high pressure, high frequency shock waves. Detonation in the latter sense is regarded by some authorities as the real cause of Detonation in the first sense, but is disputed by others.

To avoid misunderstanding, throughout the present article Knock ng is used to denote the engine phenomenon and detonation to denote the chemical reaction. (Editor.)

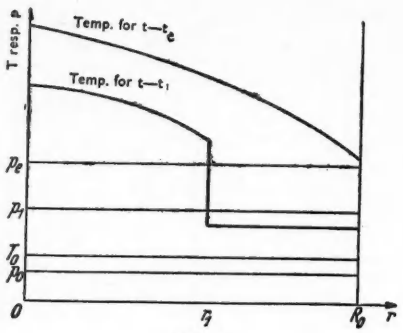


Fig. 3

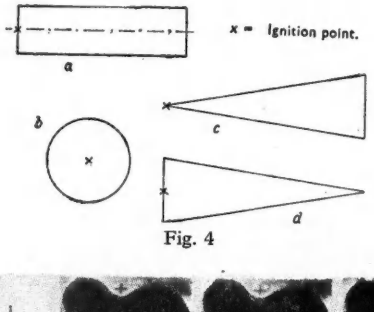


Fig. 4

charge and the heat transfer to the walls is negligible. The initial temperature, T_0, of the charge is also assumed to be uniform. Under these conditions, it will be clear that the temperature and pressure variation during the period of combustion, t_e, if plotted against the weight or volume of mixture burnt, will be independent of the shape of the combustion chamber.

In reality, however, an appreciable quantity of heat is lost to the walls. Furthermore the velocity of flame propagation is increasing as its distances increases from the point of ignition and the local temperature of the gas rises. Bearing this in mind, it should be clear that the end temperature of the end gas just ahead of the flame front is higher in a long combustion chamber (Fig. 4a) than in a compact chamber of the same volume (Fig. 4b). This is so because the high flame velocity towards the end of the combustion does not give sufficient time for heat transfer from charge to cylinder walls in a long combustion chamber. Similarly, a combustion chamber of the shape shown in Fig. 4c is more favourable than that of Fig. 4d. The compression wave set up in the first type (4c) is much smaller than in the second type (4d) since the quantity of charge burnt is smaller for the same elapse of time.

A slightly higher initial gas temperature will modify the conditions by increasing the end temperature of the charge to a much higher value. Therefore a "hot spot" in the combustion chamber, should be located as near as possible to the point of ignition. Hence it is sometimes found that a design with a longer flame path shows up better in practice than a very compact design. From the effect of hot spots the importance of turbulence becomes also apparent, especially when

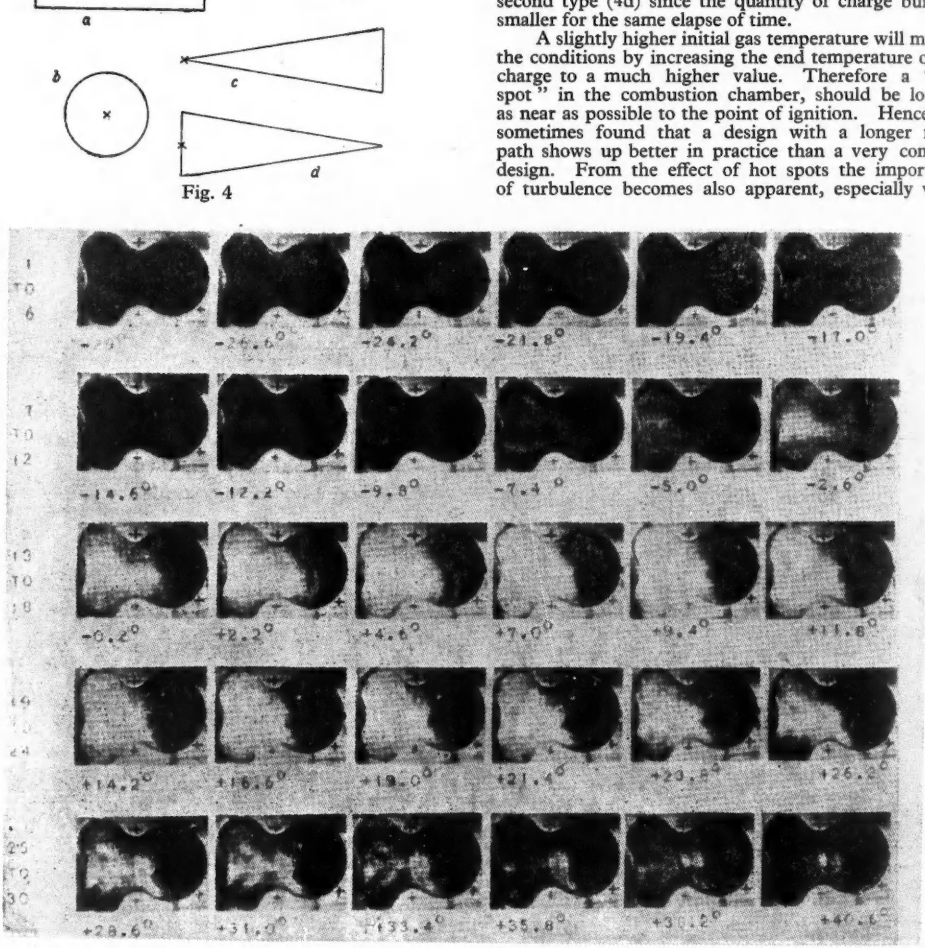


Fig. 5-6.

the hot spot is located far from the sparking plug, as it breaks up the hot air " curtain " formed.

The effect of air pockets in the combustion chamber is unfavourable as it contributes to high end temperatures of the end gas. The pockets are extensions of the main combustion chamber in which valves are usually accommodated and are, therefore, badly cooled. Exception to this is a narrow crevice, as for instance in the older type of Ricardo engine Fig. 2 where the cooling effect of the large wall surface does not permit high mixture temperatures. Pockets for the accommodation of sparking plugs have no ill effect at all.

3. Spontaneous Ignition of Residue Charge.

The thermal conditions of the end gas, as outlined in the previous chapter, are in such close agreement with the external conditions of knocking that it was impossible not to attribute great importance to ths temperature, density and pressure of the end gas ae factors starting knocking. The consequence of this was the hypothesis that knocking takes place if the temperature of the end gas exceeds a certain limiting value which depends upon the fuel and probably upon the pressure and density of the charge itself. In fact photographs have shown that with normal combustion the flame propagation is continuous from the point of origin (i.e. sparking plug), but in case of knocking combustion independent centres of ignition can be observed and eventually a spontaneous ignition of the whole of the end gas.

This phenomenon gives rise to the following questions :

(1) How is the spontaneous ignition of the end gas brought about ?

(2) Is this spontaneous ignition an accompanying phenomenon of knocking, or is it the cause of it ?

(3) If it is the cause of knocking how does it result in the harmful effects of knocking ?

By following the sequence of historical development of the question of knocking we get the answer to the last question, first.

II.—THE ILL-EFFECTS OF KNOCKING AS DIRECT CONSEQUENCE OF DETONATION WAVES.

4. Pressure rise, Pressure wave, Energy of wave.

If at any time t_1 (Fig. 3), corresponding to a flame advance $r = r_1$, the whole of the end gas ignites spontaneously, then the pressure is suddenly changed as shown in Fig. 7. This means that at $r = r_1$ a very sharp rise in the pressure occurs ($p_2 - p_1$) which sets up a pressure wave oscillating at the natural frequency of the gas charge until it is damped out. This pressure wave of a knocking combustion can be also registered by an accustical electrical indicator applied to an engine (Fig. 8) or to a bomb calorimeter (Fig. 9). That the

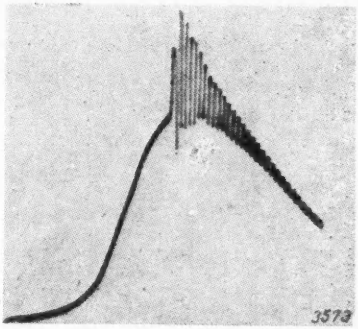


Fig. 8

typical knocking or pinking noise accompanying knocking is the sound of pressure wave impacting against the surrounding walls and not the metallic impact of the piston, as was first thought, follows from the fact that it is also audible in a bomb calorimeter where there are no moving parts.

The high frequency of these waves makes them appear to be of sinusoidal shape—as far as they can be recognized as such in Figs. 8 and 9. In reality, however, they must be high amplitude shock waves with a very steep rising branch, as shown in Fig. 10. With a high amplitude shock wave the beginning of the wave compresses the medium and the pressure peak advancing in this higher density medium proceeds at a much greater velocity ; hence the very steep branch of the wave. Fig. 11 shows the sudden pressure rise $p_2 - p_1$ in dependence of the relative proportion of the end gas. Fig. 12 shows the maximum energy which becomes available for shock wave. The maximum (curve a) occurs when 30% of the total charge ignites spontaneously as can be seen from the figure.

5. Increased Heat Transfer, Irreversible Heat Generation, Effect on Efficiency, Consumption Power and Thermal Efficiency.

Such high frequency shock waves are responsible for a strong turbulence of the gas layer in the very vicinity of the cylinder walls. According to the laws of thermodynamics this increases the rate of heat transfer to the surrounding walls. Furthermore the shock wave where it impacts against the wall will increase the temperature gradient in the gas layer (Fig. 12) and this too aggrevates the heat transfer from gas to wall. This, then, is the explanation of the general overheating taking place in an engine during knocking.

The mechanical energy contained by the (shock) wave is of course supplied by the fuel. The quantity of fuel which can be utilized for combustion is limited by the oxygen content of the charge. The energy of

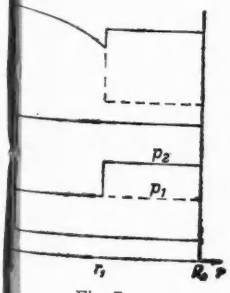


Fig. 7

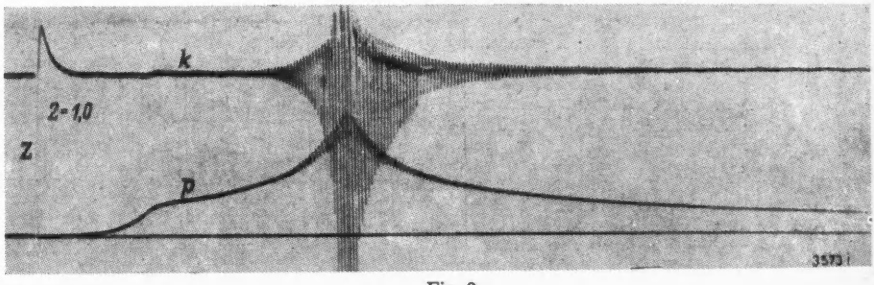


Fig. 9

detonation wave is absorbed partly by the cylinder wall and partly by internal friction within the charge ; the heat transmitted to the wall increases the heat lost to the cooling medium. The internal friction, too, is irreversible heat generation : the sensible heat extracted from the gas at a high temperature (during combustion) in the form of energy of wave is returned to the gas as internal friction at a lower temperature (during expansion). Fig. 8 shows that this return of energy takes place only late during the expansion stroke, since the detonation wave persists over a long part of the expansion stroke. Hence the whole energy of the waves is not converted to useful mechanical energy (heat energy). As a result high exhaust gas temperature and erosion of the exhaust valves is produced. The same consideration explains also why the power is reduced in a knocking engine (useful heat reduced) and the consumption increased (extra fuel needed for energy of shock wave).

From a purely thermodynamical point of view, faster combustion at constant volume, as is the case in a knocking engine, means higher thermal efficiency. Hence with very weak knocking the thermal advantages and the slightly higher c.r. value as compared with that which would be needed to suppress knocking completely, overweighs the ill-effect of heat losses just described. In fact as knocking starts (Fig. 1) the " power " curve does not fall off rapidly and the point of maximum power output lies to the right of the point which marks knocking combustion. This optimum condition cannot, however, be maintained for any length of time as the heating effect of even slight knocking slowly but gradually increases knocking (Fig. 14).

Finally the impacting shock waves have an effect like hammer blows, and explains the damages observed on pistons, etc., as far as they are not caused by overheating. This concludes the survey of ill-effects of knocking which can all be explained by the effect of the detonation wave. In view of the aforesaid the question whether spontaneous combustion is responsible for knocking must be also answered in the affirmative.

III.—THE CAUSE OF DETONATING COMBUSTION IN THE RESIDUE CHARGE.

6. Ignition by overheating.

The question may be asked whether the previously mentioned general overheating of the engine does not occur prior to knocking and cause spontaneous combustion. The answer to this question is definitely negative, because overheated walls cannot start knocking combustion. Pictures of flame propagation, too (Fig. 5-6) show points of ignition in the charge which then bring about a very rapid combustion. As these points of ignition do nor occur at the same spot in consecutive cycles of combustion, it must be concluded that local heating effect cannot be responsible for it.

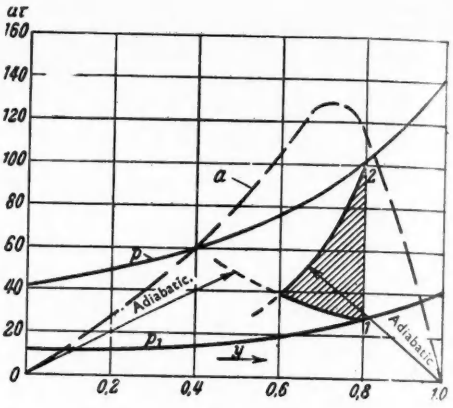


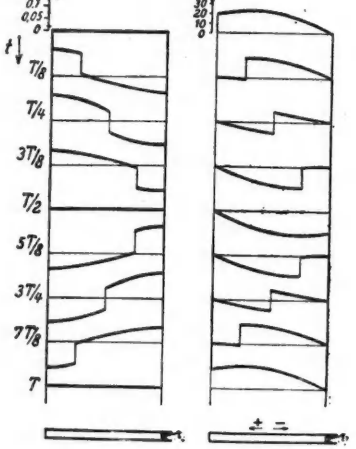
Fig. 12

Having eliminated overheating as a possible cause of knocking, there are two main theories left to consider : Theory of Detonation (Berthelot's wave) and the thoery of compression-ignition. Before going into details of these two theories, it is essential to discuss briefly the effect of flame propagation upon the pressure in the cylinder.

7. Pressure effect of flame-front.

From the flame-front a continuous pressure wave is omitted which travels at the velocity of sound to both ends of the combustion chamber. With a progressing flame-front, however, not a single pressure wave is generated, but shock waves in quick succession. This can be better understood from the following consideration :

If at point I (Fig. 15) a small quantity of gas is



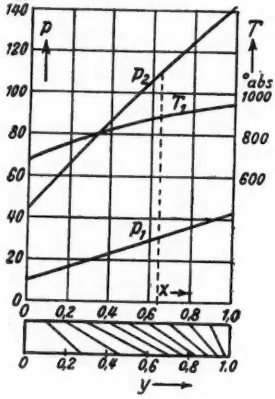
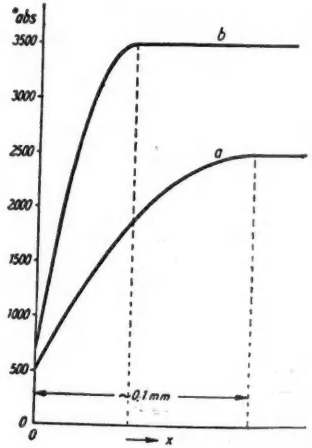


Fig. 10 (left) ; Fig. 11 (in the middle) ; Fig. 13 (right)



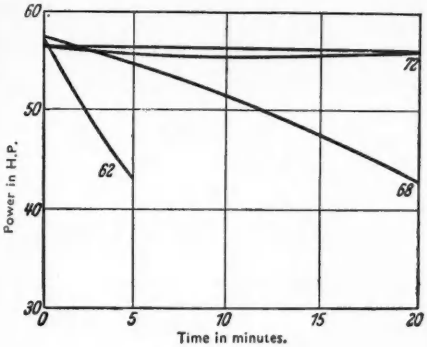


Fig. 14

burnt, then a local pressure rise is caused (Fig. 15a) and the pressure wave set up in this way travels at the velocity of sound (Fig. 15b). The amount of pressure increase at point I, depends upon the quantity of gas involved, after the combustion of which the pressure drops again as shown in (Fig. 15c).

If the velocity of flame propagation is less than the velocity of sound, then at the instant represented by Fig. 15b the combustion has only advanced to point II (15c) while the pressure wave has reached point III. This means that the new pressure wave originating from point II can only partly strengthen the frontal branch of the first wave; in part it coincides with the following branch of wave I (Fig. 15b). Now the same argument holds good as in paragraph (4). The strengthening of the frontal, rising ordinate of the wave I prepares the way for a higher velocity of sound for the latter part of wave II, so that here too the frontal parts of waves I and II are turning to steep shock waves (Fig. 15c). The reversed effect takes place at the falling branch of wave I, as the combination of waves I and II tends to produce a flatter curve.

It follows, therefore, that shock waves are omitted from the advancing flame front, the steep frontal branch of which is developed only some distance ahead of the flame front. It must be also concluded from Fig. 15 that the amplitude and wave length of these shock waves must be small if the flame velocity is small compared to the velocity of sound. This follows from the fact that the length of the shock waves depends in the first place upon the distance covered by the pressure wave I, while the flame is advancing half a wave length. This distance becomes small provided the velocity of flame propagation is also small. With increasing flame

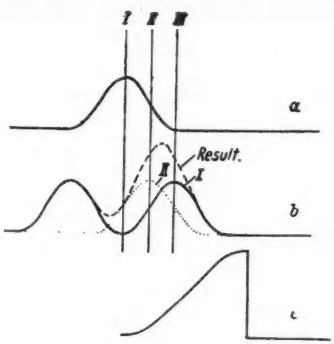


Fig. 15

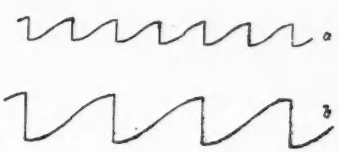


Fig. 16

velocity the wave length and amplitude of shock waves is also increasing (Fig. 16a and b).

According to Becker, shock waves advance at supersonic speeds; in particular, the velocity is the higher the larger is the amplitude of the shock wave. The temperature rise cause by such waves is accordingly also higher than that due to an adiabatic compression. In place of the adiabatic equation the so-called "Hugoniot" equation is substituted, which for small pressure charges, $p_2 - p_1$, becomes identical to the adiabatic equation. However, with shock waves extremely high temperatures can be recorded: As an example for air at $T_1 = 273°$;

Pressure rise with shock wave P_2-P_1	2	5	10	50	100	1000	2000
Temperature T_2 with shock wave	336	482	705	2260	3860	19100	29000
Temp. T_2 accord. to the adiabit. equat.	330	426	515	794	950	1710	2070

DETONATION. (BERTHELOT'S wave).

If a combustible mixture enclosed in a long tube is ignited at one end, and, the flame front will gradually progress through the whole of the mixture which is below the self ignition temperature. The mechanism of this process is simply an impacting of molecules along the flame front and thus initiation of chemical reactions. As the energy of the molecules is continously increasing, more and more molecules are incited to reaction.

Provided that the flame travel is slow compared to the velocity of sound, there is ample time given for the pressure wave to be damped out so that a uniform pressure rise can be noted throughout the mixture. However, this is also accompanied by a gradual rise in temperature and eventually self ignition temperature is reached. At a certain instant a small further increase in temperature will suffice to cause a spontaneous self-ignition of the end gas. This self-ignition will actually be the result of a shock wave and the locality will probably be a short distance ahead of the flame front, where the full effect of the shock wave can develop. This point marks a new centre of ignition and the flame ensuing from here traverses the rest of the mixtures at a supersonic velocity. This sequence of events is termed "detonation."

The velocity of detonation has been determined almost at the time of its discovery (Berthelot, 1881)

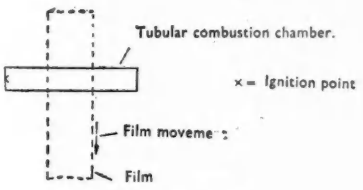


Fig. 17

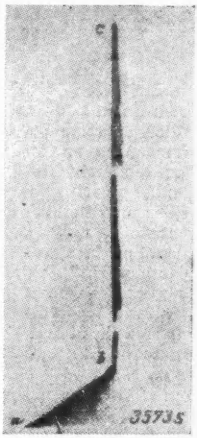


Fig. 18

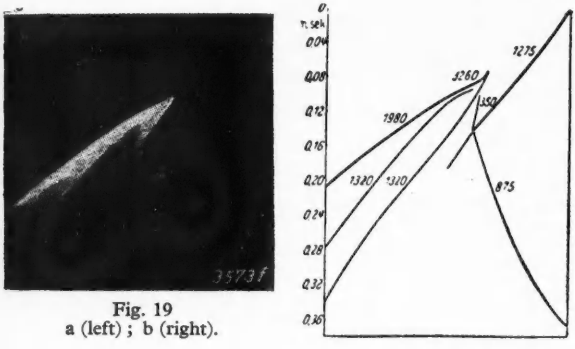


Fig. 19
a (left) ; b (right).

and has been recorded on photographs in a manner outlined in Fig. 17. The method consists essentially of passing a strip of film over a tube made of transparent material and recording the interior happenings. As the film moves in the direction of the arrow, the slope of the line traced by the flame (Fig. 18) is an indication as to the velocity of combustion. Fig. 18 shows clearly the sudden increase of the detonating wave velocity, b-c, as compared to the normal flame velocity, a-b. By suitably increasing the film velocity it is also possible to show the detonation as it starts some distance in front of the ordinary flame front, Fig. 19.

The velocity of detonation can be also calculated as being between 1,000 and 4,000 m/sec. A close agreement between measured and calculated values exists. An interesting feature of detonation becomes apparent from calculating its velocity: This tends to a constant value, and if for instance detonation starts at a higher speed, it decreases gradually to this value.

9. Other Type of Shock Wave Ignition of the Residue Charge.

Very rarely a secondary flame front is started by a wave reflected from the cylinder wall. In such instances the knocking starts at the far end of the combustion chamber or tube. This type of ignition occurs only in combustion chambers of complicated shape where reflected pressure waves are crossing one another's path. This case provides a transition to the thoery of Compression-Ignition.

10. Compression-Ignition.

This theory is based on the assumption that as a result of the pressure and temperature rise the residue charge is brought finally to a self ignition temperature when spontaneous ignition occurs. In practice, however, such a simultaneous ignition is inhibited by turbulence and other circumstances which increase the temperature at one point but decrease it at another point. As an example, during the suction stroke a part of the charge comes into contact with the hot cylinder walls and although it is subsequently mixed with the rest of the charge it will still form nuclei of hot particles. The difference in temperature between individual parts of the charge is further aggravated as the pressure is increased since some of the particles have a higher initial temperature. Consequently, at the instant when detonation starts, the temperature of the end gas is not homogeneous but as shown in Fig. 20, T_3. The hot nuclei in the charge reach self ignition temperature first (Tz) and initiate an almost spontaneous ignition in the rest of the charge.

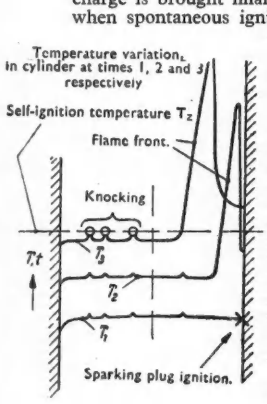
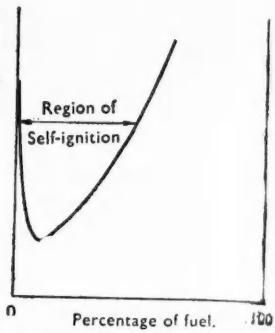


Fig. 20

Fig. 21



Very similar is the case regarding chemical homogeneity. A physico-molecular consideration of the self ignition temperature defines the lower limit of chemical homogeneity as that limiting composition which just ensures that combustion—once started—will continue in the mixture. As can be seen from Fig. 21, the chemical composition is of considerable importance from the point of view of self-ignition.

Contrary to the theory of Detonation, this theory shifts the emphasis on the general temperature and pressure rise of the mixture and not on the effect of the shock wave ; nor does it suggest that knocking combustion proceeds at supersonic speed. If on the other hand it is assumed that the mutual effect of shock wave and hot nuclei of the charge, which are especially apt to self-ignition, produce a secondary ignition, proceeding at a high but not supersonic speed, one arrives once more at the theory of shock wave ignition without detonation, which takes up an intermediary position between the theory of Detonation and the thory of Pressure-Ignition.

11. Criticism, Engine Observations.

Considering the conditions in an engine, it is not possible to decide which of the theories discussed is the correct one. As an example, a point usually held against the Detonation theory is that detonation wave in tubes require a " running start " of about 25–150 cm. However, there is no proof that such length of a running start is needed in an actual engine, too. Another, more serious objection against the Detonation theory is that detonation cannot be produced in tubes when the mixture used is identical in composition with that in engines. At the present, it is not yet possible to determine the real cause of this. Calculations have shown that detonation waves become stablized only if the rate of chemical changes become very high.

Recently investigations were carried out to determine whether the combustion of hydro-carbons is linked

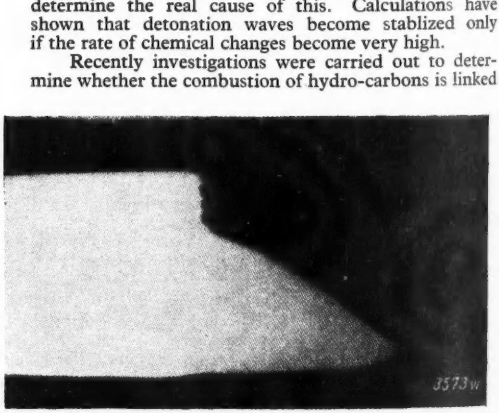


Fig. 22

with the production of intermediary products or with preliminary reactions before actual ignition takes place, the product of which might act as carriers for detonation waves. More information on this question will be given below.

The reason for such a thorough investigation of knocking and the accompanying flame and shock wave effect is probably due to the fact that in a publication of engine research on the "knocking" phenomonen, Ricardo used the term "Detonation." It is doubtful, however, whether Ricardo had real detonation waves in mind. As a matter of fact other theories can show many points in their favour.

Fig 5-6 shows ignition centres in the knocking gas which is hardly in accordance with the theory of Detonation. Recently tubular combustion chambers were fitted to engines and observation windows provided. The ignition plug was arranged at one end of the tube and pictures of the detonating combustion taken, Fig. 22, showing a typical picture. The individual centres of ignition can be distinguished in this picture (Note the zig-zag shape at the beginning of combustion in the residue). Considering that Fig. 22 shows the detonating flame front to a considerable depth of the combustion chamber, eventually so many points of separate ignition might appear in the picture that the impression would be that of simultaneous ignition in the whole of the end gas. Moreover, as lower temperature may prevail at the far end of the tube due to cooling by the walls, this might be responsible for the impression given as if the front of the detonation combustion was continuous and inclined towards the transversal axis of the film, indicating the presence of real detonation. This would also explain why such high flame front velocities are found: The inclination of the "flame front" can be mistaken for the rate of flame propagation. From such measurements velocities up to 500–900 m/sec. can be obtained which are still below true detonation velocities, i.e. 1,000–4,000 m/sec.

Even if this principal defect of the method is disregarded, it can still be argued that the film velocity is far to small to measure flame velocities up to 1,000 m/sec. especially as the outer edge of the flame front is not well defined and a tangent can therefore not be drawn with any degree of accuracy.

In another series of experiments, 24 lines of paths of ionisation have been arranged in a cylinder, and the flame propagation recorded. According to this method, the velocity of flame propagation of a detonating combustion in only 300 m/sec. However, this method too fails to give conclusive results in consideration of the indirect method of velocity measurement and other unknown factors existing.

It appears that the best method for investigation

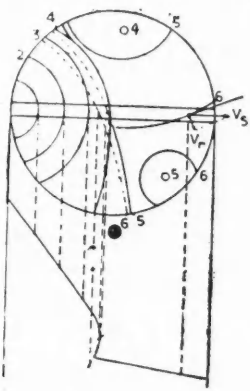


Fig. 23

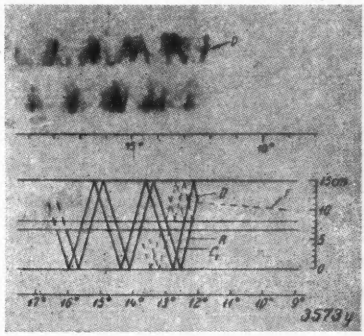


Fig. 24

of such nature is by photography as shown in Fig. 5-6. Better results could be arranged if the film velocity could be increased. As was mentioned before, these pictures show it, too, that in the knocking end gas there is no secondary flame front proceeding from the primer flame front, but that the secondary ignition is initiated in the residue itself. The velocity of the secondary flame front is very high but not in the neighbourhood of 500–900 m/sec. A series of photographs has been obtained, as a matter of fact, according to the method of Fig. 17. From these pictures flame velocities of 2,000 m/sec. can be established, and hence assumed to be real detonation waves. The authors of these measurements claim to recognize the starting point of the detonation at some distance ahead of the primary flame front (Fig. 24). The criticism of this method is that observation was not possible in a large section of the combustion chamber. The sparking plug is located at the left centre of the window, Fig. 23, and the flame starting from here proceeds according to points 2, 3, 4. If at this instant, Time (4), a new centre of ignition is formed at the top centre and at the bottom centre at instant 5, invisible on the film, and if secunder flames propagate from these newly formed centres at high but normal velocities (lines 5 and 6) then along the window the irrational flame velocity, Vs, can be observed. The true flame velocity is, however, Vr. This would explain, otherwise than by detonation, how such high (2,000 m/sec.) flame velocities can be observed through the window.

12. Two Recent Investigations.

The flame velocity was measured in a bomb calorimeter and an actual engine cylinder by the ionisation method, Fig. 25. True detonation in the calorimeter

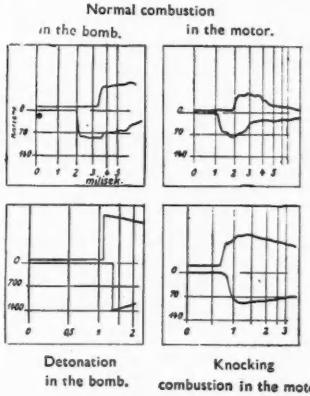


Fig. 25

shows—in spite of an enlarged time base—an infinitely rapid rise of electric conductivity. Knocking combustion in the engine, however, failed to register such a high flame velocity. It rather shows a flame velocity of normal combustion in both the calorimeter and engine.

A piezo-accustical indicator was also used to investigate detonation in a calorimeter. All possible conditions of mixture and its initial condition have been considered. By this method apart from detonation, three distinct types of "knocking" combustion could be distinguished.

(*a*) With normal combustion at low initial temperatures knocking occurs which under certain conditions of flame velocity and combustion chamber design, by means of resonance produces a high amplitude pressure wave. This is a short lived phenomenon, however, and has no material influence upon combustion.

(*b*) At elevated initial temperature or if richer charge is used, the velocity of combustion is increased and secondary ignition takes place at the remotest place from the ignition plug. This is accompanied by a violent shock and audible pinking noise.

(*c*) At high initial temperatures, secondary ignition of the charge occurs near the centre of the end gas. This is accompanied by a shock wave and pinking noise as before.

The conditions leading to (*a*) and (*b*) do not appear to be given in engines. The typical pinking noise is present in every case and is further proof that the detonation waves are themselves responsible for this.

Because of the complications resulting from knocking of hydro-carbons usually employed pre-reactions are suspected to be responsible for an intermediate product of combustion which would serve as a carrier for knocking. The following points should be noted in this connection.

The theory of Detonation alone is capable to give a satisfactory answer to the question why there are secondary flames—travelling at a velocity many times that of the primary flame front—in the end gas. Adiabatic compression is hardly responsible for this, since it is a gradual process and, therefore, the primary flame front should also reach the same high velocity at the time when secondary ignition occurs. For this reason it is suggested that the end gas is brought to a condition by means of preliminary reaction (not accompanied by visible flames) which permits a much higher flame velocity than the unprepared mixture. With this theory two questions arise: How do the pre-reactions occur and why are these affecting only the end gas?

Pre-reactions are probably dependent on a critical temperature. As soon as this temperature is reached, a combustion takes place which is not accompanied by visible flaming perhaps because the heat generated is insufficient for that. Alternatively it is possible that the combustion is endothermic and produces only a partial transformation of the hydro-carbon molecules. Long ignition lag periods seem to indicate that such pre-reactions take place and are especially marked with hydro-carbon mixtures.

Other investigations, too, have proved that adiabatic compression cannot produce such high temperatures which are observed in knocking mixtures just before knocking starts. These experiments seem, therefore, to indicate that pre-reactions must contribute to temperature rise before true ignition occurs.

The author of this article wishes, therefore, to point out the following.

The shock wave originating from the flame front raises the temperature of the end gas above the adiabatic range as shown in Fig. 3. A point will be reached when the next shock wave will just suffice to raise the temperature to a critical value, and start pre-reactions. The latter prepares the residue charge for the high velocity of the secondary flame front and hereby to a rapid combustion or detonation. The secondary points of ignition, Fig. 5-6, are then resulting from a further shock wave, or from the superposition of shock waves, or from self ignition, or from the production of intermediary products. Lack of homogeneity of the mixture and temperature is also playing a part in this process.

Although injecting artificially shock waves into normal combustion, does not produce detonation, this should not be regarded as proof that detonation is not accompanied (or caused) by shock waves. On the contrary, there should be no doubt any more that shock waves are inherent to knocking combustion; theory and practice seem to agree on this point and even quantitative measurements are possible. That the shock wave preceeds chemical reactions is evident from the fact that the velocity of detonation which is often higher at the beginning but corresponds to the velocity of the shock wave is reduced subsequently to a more stable velocity which occurs in conjunction with combustion.

But if the shock wave occurs prior to chemical reactions then it is difficult to understand why the primary flame front is emitting a shock wave just at the instant when the end gas has reached a condition ready for simultaneous combustion and transmission of shock waves. It is more likely that shock waves are emitted continously and are equally important for knocking and detonation. This gives also a simple explanation of the above mentioned observation that namely artificial shock waves do not produce detonation. If, namely, shock waves are preparing the end gas for detonation, and if the engine conditions are otherwise unsuitable for this, the artificial shock waves cannot produce detonation.

As a conclusion it can be said that the question of knocking is still far from being completely understood. There are still many problems related to knocking requiring a satisfactory explanation.

The article is concluded with a Bibliography mentioning 41 books, papers, and articles relating to its subject-matter. Space does not allow publishing this Bibliography within our abstract, which is, however, available to our Readers free of charge.

IGNITRON RECTIFIERS IN INDUSTRY

By J. H. Cox and G. F. Jones.* (From *Electrical Engineering*, Vol. 61, October, 1942, Transactions, pp. 713-718)

First applications of ignitrons were in transportation service in mines and railways. Since then, as superior operating results became known, more than 2,000,000 kW of ignitron-rectifier units have been installed by the electrochemical industry. Some features of installations for large power concentration are discussed in this paper.

* Both authors are with Westinghouse. El. & Mfg. Co., East Pittsburgh.

Continuously pumped ignitrons are manufactured to date in four sizes which in six tube assemblies have continuous ratings at 600 volts of 1,250, 1,667, 2,500 and 4,000 ampere. The 2,500-ampere size has been applied in greatest numbers. However, the majority of applications has been made using 12-tube assemblies.

The ignitron consists of a drawn steel tank with a removable cover plate into which is mounted the main

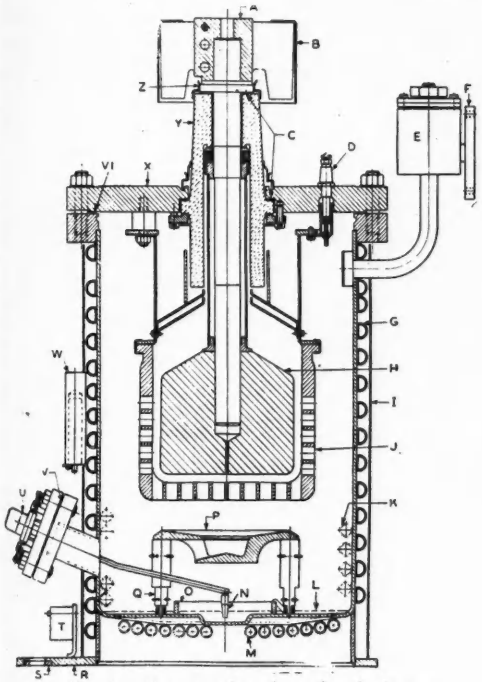


Fig. 1. Cross-section view of an ignitron.

A Anode radiator and terminal	M Cathode-cooling coils
B Radiator cover	N Ignitortip
C Asbestos seal	O Quartz ring
D Shield entrance bushings	P Baffle
E Tank valve	Q Quartz tube
F Vacuum manifold connection	R Steel plate
G Tank-cooling coils	S Copper insert
H Anode head	T Terminal block
I Tank cover	U Ignitor entrance assembly
J Anode shield	V, V_1 Aluminium seal rings
K Internal cooling coils	W Thermal switch
L Mercury cathode	X Anode plate
	Y Anode porcelain
	Z—Solder seal

anode bushing and anode shield terminal. Anode, deionizing shield surrounding the anode and the baffle between anode and cathode pool are of graphite. The baffle is insulated from the cathode. The tank itself constitutes the cathode connection and is bolted to the cathode copper bars on the assembly frame. The ignitron is mounted on a rod, which passes through the side of the tank, insulated with a glass-kovar-seal on a flexible steel diaphragm. The ignitron can be adjusted from outside by adjusting screws. A small solid radiator terminal holds the seal of the main anode bushing within safe temperature. Enamelled aluminum wire rings are applied as vacuum sealing gaskets in the separate joints of the ignitron proper. The external connections to the vacuum pumping system which operates at low temperature are gasketed with iron-band-protected rubber.

The ignitron tanks are cooled by water passed through copper tubing attached to the steel with high temperature solder. Additional cooling in high current units is provided by an internal copper lined steel coil, all water-cooled surfaces being made non-ferrous. Details of the design can be seen in the cross-section view Fig. 1 and the external view Fig. 2 of the ignitron described. An assembly of 12 ignitrons rated at 5,000 ampere d-c in the 600-volt class is shown in Fig. 3.

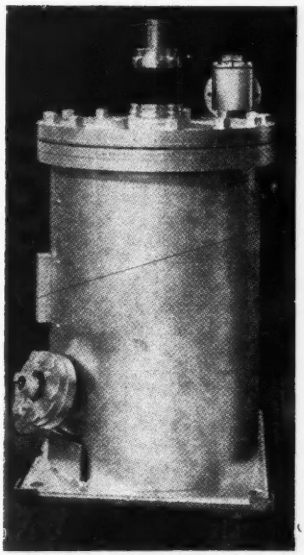


Fig. 2. External view of a single ignitron.

One, two or more rectifier assemblies may be connected to one transformer. Where the power required can be supplied with six anodes or where the small number of units suggests sectionalization to insure continuity of service, ignitrons are assembled in groups of six on one frame with one cooling system and one vacuum pumping and measuring system. However, in large stations simplicity dictates assembly in units of 12, as shown in Fig. 3. The individual tanks are connected to the vacuum pumps through a vacuum manifold with water-cooled pumping connections which condense the mercury vapour and prevent transfer of mercury between tanks and pump. On these large-size tubes an individual vacuum valve on each facilitates manufacture and repair. One ignitron tube can be interchanged with a spare in less than one hour if necessary. Fig. 4 shows a typical ignitron installation comprising 12 ignitrons assemblies in an electrochemical plant.

Since cooling water which is pure enough to pass through the rectifier jackets or tubes directly is rarely available, practically all installations are provided with heat exchangers which permit the recirculation of pure or treated water. Water-to-water or water-to-air exchangers may be used.

The earlier types of ignitron excitation which utilized thyratron tubes have mostly been superseded

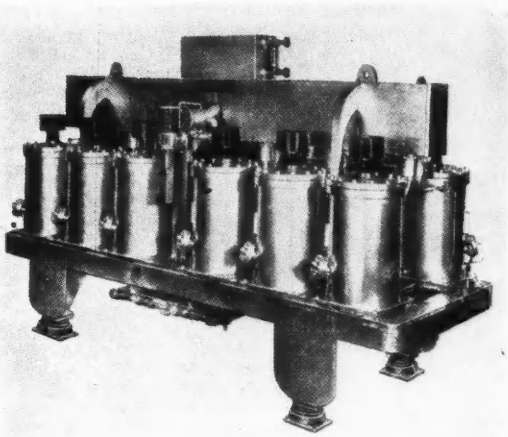


Fig. 3. An assembly of 12 ignitrons rated at 5,000 amperes d-c in the 600-volt class.

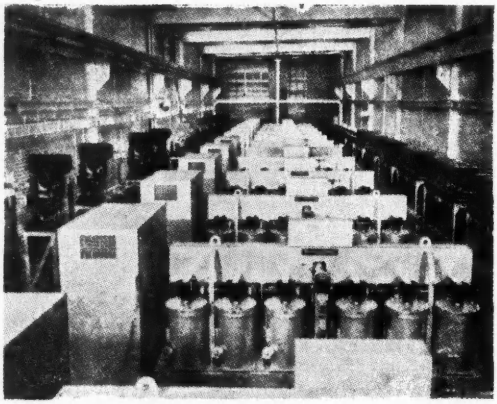


Fig. 4. Typical ignitron installation in an electrochemical plant.

by circuits which generate impulse voltages by means of saturating reactors, utilizing static devices throughout.

Two types of phase control of rectifier voltage have been used. One is a mechanical phase shifter, which consists of a wound-rotor induction machine. The phase position of the excitation impulses is determined by the position of the phase-shifter rotor in its stator. This position is controlled by a fractional-horsepower motor through a gear box. The other type of phase control utilizes some form of phase-shifting network. The latter system is more flexible, where automatic control is required and speed of response is important. Also, such a network may be designed to include voltage-compensating characteristics which will maintain full energy excitation through supply-line voltage fluctuations as great as 50 per cent.

Station Layout.

Fig. 5 and 6 show a typical multiunit station layout having the simplest and most economical arrangement of apparatus giving a straight line run of power from the a-c supply source to the d-c bus.

For the layout shown, the a-c switchgear is a small masonry house separated from the main building: Outdoor switchgear, outdoor metal-enclosed gear or switchgear located in the substation building may be used as well. All transformer equipment is outdoor. Outdoor bus structure or underground connections as shown in the figure may be applied.

The main building has two levels. The ignitrons and all control devices are located on the operating floor, some accessories and low voltage switchgear in the basement. All apparatus in the basement are operated electrically from the operating floor. In many installations the low-voltage switchgear is also located on the operating floor.

Some detail equipment which can be located as convenient is not shown in Fig. 5 and 6. A repair bay is usually provided at the end of the substation building, suitable for untanking even the ignitron transformers. An enclosed clean room for working on interior parts of rectifiers is desirable.

Usual switching arrangements for ignitron units rated at 8,000 to 10,000 amperes in the 600 voltage d-c class are shown in Fig. 7.

Arrangement A: No circuit breaker between a-c bus and transformer, as the concentration of power supply would require large rupturing capacity. Primary switching is done by the disconnecting switch which is capable of opening the transformer magnetizing current. Primary faults must be cleared by the switchgear in the supply circuit to the plant. This involves plant shutdown until the faulty circuit is isolated by operation of the disconnecting switches.

The secondary switching consists of high-speed anode switchgear with one pole for each phase of the transformer secondary. High-speed switching which will limit the d-c rise in the average circuit in the order of one-third cycle, on a 60 cycle basis, is essential for large multiunit substations. At the time of arc back, all normal units will contribute direct current to the arc back in the form of reverse current. This current increases rapidly, depending upon the inductance of the circuit, and must be limited by the switchgear to a value which the switchgear can open successfully and without undue maintenance and stresses on the other equipment involved in the circuit, particularly the transformer.

When an arc back occurs, the sound anodes of the ignitron assembly involved will supply current to the faulty anode. This feed to the arc back is a short circuit, through the arcs involved, on the transformer secondary and must be suppressed by opening the a-c supply to the transformer or by opening the faulty

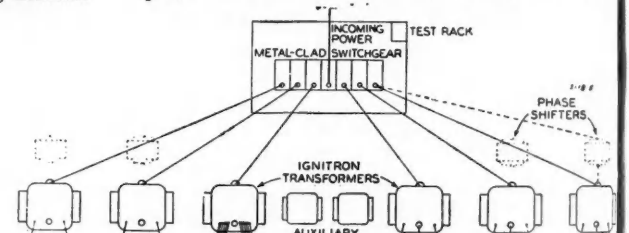


Fig. 5. Plan view of a typical multiunit ignitron substation.

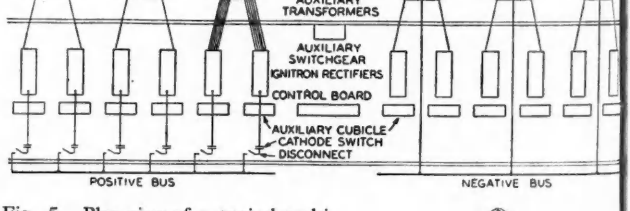


Fig. 6. Elevation of a typical multiunit substation.

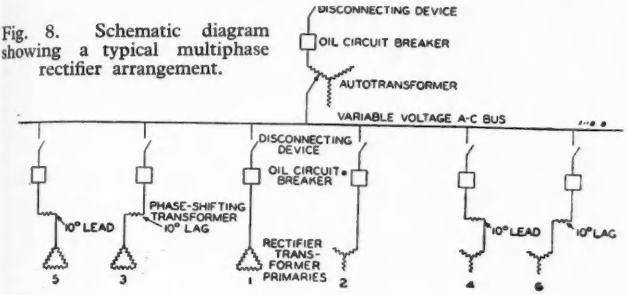
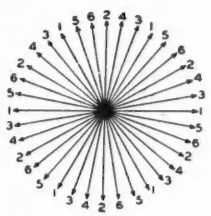


Fig. 8. Schematic diagram showing a typical multiphase rectifier arrangement.



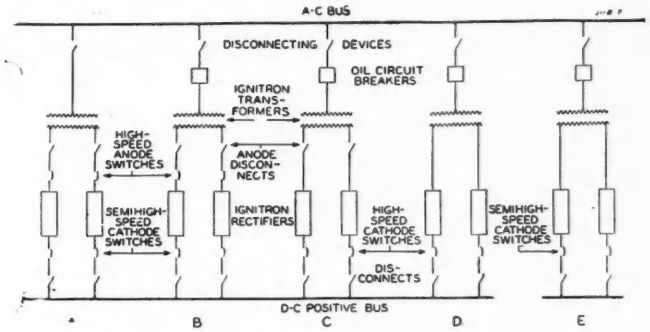


Fig. 7 (right). Schematic diagrams showing various arrangements of rectifier switching.

Where a complete unit outage is permitted because of spare capacity available, the anode disconnecting switches can be omitted. This applies to arrangement A, B and C and is shown in D. For a single rectifier unit supplying an isolated d-c bus a semi high-speed cathode switch and disconnecting switches may provide satisfactory operation. When continuous service in such a plant with only one unit is an absolute essential, high-speed anode switching can be arranged to trip individual poles and on reverse current only. At the time of arc back only the pole of the circuit involved in the fault will open, the other anodes continuing in service.

Where the normal five to eight per cent. shunt characteristic of non-controlled rectifiers is not sufficient, one of the phase control systems is used. There is a wide choice of control method, ranging from manual to fully automatic. Compensation of a-c voltage loss in feeding line can be provided and d-c voltage can be adjusted according to d-c load.

In large stations containing many units phase control is used to equalize the currents in the several units and to provide small variations in voltages as desired. However, since large phase control angles adversely affect power factor and increase harmonics, the minimum feasible transformer tap is used in order to keep the phase control angles at a minimum. Various combinations of transformer taps, autotransformers and phase control are used in order to enable adjustment of the voltage to the individual demands of the electrochemical process concerned without long time wide range voltage adjustment by phase voltage control.

Some processes require that constant current be maintained through the electrolytic cells. This can be achieved in many cases by appropriate taps and tap changing equipments so that phase control of voltage is not required between taps or, if used, will be limited to a few per cent. in range. But the attempt to maintain constant current had to be abandoned, where the frequency of tap changing was prohibitive and phase control angles to large.

However, tap changing can be used to secure constant kW—input to the cells, insuring maximum production at the normal power rate and avoiding higher annual rates in case of short time swing over the demand ceiling.

circuit between the transformer and the ignitron. For arrangement A the a-c supply to the transformer cannot be opened except by operating the circuit breakers in the station supply. High-speed anode switching is therefore essential for this circuit. The anode circuit breakers are supplemented by semi high-speed cathode circuit breakers. These are used for normal switching operations. Disconnecting switches permit maintenance of the circuit breakers with a minimum of equipment out of service.

Arrangement B: This arrangement can be recommended if the rupturing capacity of the oil circuit breaker required is 500,000 kVA or less. The circuit breakers are then relatively inexpensive and each ignitor circuit is completely independent of the others. The use of high-speed anode switching makes it unnecessary to open the oil circuit breaker at the time of arc back.

Arrangement C: This circuit is similar to circuit B except that high-speed anodic switches are omitted and a high-speed cathode circuit breaker is substituted for the semi-high-speed switch. Arc back is opened with high-speed action by the cathode circuit breaker.

Arrangements B and C differ in so far, that in B there are six poles of anode switchgear to maintain compared to a single larger pole of cathode switching in C. The choice between the two arrangements is therefore dictated by consideration of maintenance, as compared with an occasional failure to segregate the fault in a half-rectifier unit.

In arrangement C the primary oil switch unit must be interlocked with the cathode switch, so that the entire unit is removed from service in the event of arc back. The disconnecting switches in the anode circuits to each ignitron section are used so that each assembly can be isolated for maintenance and continue with normal operation of its associated assembly.

The loads on the large station buses constitute practically a short circuit for a single rectifier unit. Therefore, it is not possible to place units on the bus individually at full voltage following a station outage. Where the power supply system is large with respect to the station to be connected to the system it has been general practice to connect all units to the power supply without excitation and then to close the excitation contactors to all units simultaneously with a master control switch. When the supply system is not adequate for this procedure, all units are connected to the bus either simultaneously as above or individually but with phase-delay angles set uniformly to limit the station current to a value satisfactory to the supply system or to the rectifier unit, depending on the procedure. The phase control angles are then advanced uniformly on all rectifiers units to increase load to normal at a rate satisfactory to the supply system.

The harmonics created by the rectifiers in the a-c system to which they are connected, may become the origin of serious telephone interference, especially when the rectifier load is a large percentage of the system load in the exposure area. For electrolytic plants exposures between the d-c circuits and telephone lines are easily considered. This is not the case in regard to the interference with supply a-c systems.

The number of phases at which any rectifier unit can operate, cannot be greater than the number of anodes of the unit. Small units having six anodes are therefore limited to six phase operation. As the number of phases in multiple of six is increased, some of the base harmonics of six phase operation are cancelled, the cancelling increasing as the number of phases is increased. Operation of rectifier units in the higher multiphase relationships, therefore, decreases the telephone interference problem.

For installations which have a large number of rectifier units multiphase operation can best be secured by operating the units out of phase with respect to each other and in symmetrical relationship. Fig. 8 shows the circuits to the primaries of six rectifiers to secure 36-phase overall plant operation. Supply voltage to some rectifier transformers is shifted by the use of phase-shifting transformers. Experience to date has demonstrated that 36-phase operation gives satisfactory operation from the interference standpoint in most cases. However, for very large and concentrated rectifier installations operation at 72 or 108 phases may be of advantage.

If one rectifier unit in a multiphase set-up is taken out of service, an unsymmetrical phase relationship will result. Under this condition, a 36-phase arrangement gives just as good results as a higher numbered phase arrangement. Operation with one unit out of service gives reasonably satisfactory results.

HOW TO SELECT, INSTALL and MAINTAIN ARC-WELDING SETS

By R. F. WYER, Electric Welding Section, Industrial Department General Electric Company. (From *General Electric Review*, Vol. 45, No. 8, August, 1942, pp. 438-442).

WHILE to-day's arc-welding sets represent the highest in simplicity and reliability, they will require periodic attention from a maintenance standpoint if they are to be kept in the best operating condition. A systematized maintenance program will pay dividends in terms of better welder performance and longer life.

Selection and Installation.

Selection.

To insure proper choice of the rating of a single operator set, the maximum current, load voltage, and duty factor (ratio of arc time to total time) must be taken into account. Except in the smallest sizes, most sets are rated on a one-hour load. Their rating is the current which they will deliver for one hour without interruption, and without exceeding a prescribed temperature rise.

Since this method of rating, chosen as a simple standard for comparison, does not take into account actual operating conditions, it is not always economically sound to choose the size next larger than the maximum operating current contemplated. However, for the same reason duty factor should be taken into account when new equipment is being considered to make certain that the set is big enough for the job.

Installation.

In wiring up a welding set, care should be taken to provide adequate branch-circuit conductors, and fuse clips large enough to accommodate the necessary fuses. It should be observed that motor-generator-type welding equipments have full-voltage motor starters almost without exception, so that due consideration must be given to the starting current of the motors.

Care should be taken to ground the frames of all welding equipments in order to avoid shock or annoying tickles when a grounded person touches the frame of the equipment. Even with equipment in perfect operating condition, under some circumstances it is possible a harmless but irritating sensation of shock from ungrounded equipment, due to the passage of leakage or infinitesimal capacity currents. In addition to protecting against this annoyance, adequate grounding of machine frames is also a desirable safety precaution against harm resulting from insulation failure in equipment or leads, or improper connections.

Regardless of the type of safety ground connection which is installed, adequate low-resistance work leads should always be used, and care should be taken to secure good connections between the work lead and the work. If this is not done, it is possible under some circumstances for the safety ground connection to become overheated, as a result of welding current passing through it.

In the location of welding equipment, ventilation is a very important consideration. The life of electrical insulation is seriously shortened by overheating, and overheating is bound to result where insufficient ventilation is provided. In some instances, it is desirable to provide exhaust fans to assist in removing heated air and in keeping the ambient temperature below 100 F.

Inspection and Regular Servicing.

Records.

The competent maintenance man will have a record of all welders under his care. All repair work, with its cost, can be entered on the record, and any welder requiring excessive attention or expense can be investigated and the causes determined and corrected.

Inspection records will also serve as a guide to tell when welders should be replaced because of the high cost to keep them in operating condition.

Motor Inspection and Maintenance.

A systematic and periodic inspection of motors and generators is necessary to insure best operation. Most machines are located where some sort of dirt accumulates on the windings, and this lowers insulation resis-

TABLE 1.—COMMON ARC-WELDER TROUBLES AND THEIR REMEDIES

Trouble	*Cause*	*Remedy*
Machine fails to hold heat	Rough or dirty commutator	Commutator should be trued or cleaned
	Brushes may be worn down to limit of adjustment or life	Replace or readjust brushes
	Brush springs may have lost adjustment or may be broken	Replace or readjust brush springs
	Field circuit may have variable-resistance connection or intermittent open circuit	Check field current with ammeter to discover varying current. This applies to both the main generator and exciter if used
	Electrode lead or work lead connections may be poor	Tighten all connections
	Wrong grade of brushes may have been installed on generators	Check with manufacturer's recommendations
	Field rheostat or tap switches may be making poor contact and overheating	Inspect rheostat and clean and adjust finger tension on switches
	Brush-shifting or other mechanical current-adjusting mechanism may have loose or worn links	Check current-adjusting mechanism for back-lash and play
Motor trips off line	Power circuit may be single-phased	Check for one blown fuse or dead line
	Welder may be operating above current capacity	Check load against welder nameplate. Check duty cycle
	Welding electrode or work leads may be too long or too small in cross section	Check terminal voltage while machine is loaded; it should not exceed 30 volts on small machines or 40 volts on large machines when operating at rated current
	Ambient temperature may be too high	Make sure that temperature in motor-generator room or housing does not exceed 100 F and that there is no interference with normal ventilation of the machine
Machine fails to start	Power circuit may be completely dead	Look for open disconnect switch, fuses removed from clips, or blown fuses
	Power circuit may be single-phased	Look for one blown fuse or one dead line
	Power-line voltage may not be suitable for motor, or may be extremely low; may be accompanied by chattering of the motor starter	Check voltage with voltmeter, particularly at the moment of attempted starting
	Machine may be jammed	See that armature turns over easily by hand, and look for foreign material in air gaps
	Motor starter may be single-phased	Check to see that all fingers on starter make contact when closed
	Overload protecting relays may be tripped	See that relay contacts are closed and that starter picks up when push button is pressed. Be sure to remove cause of tripping
Welder starts but fails to generate	May be running the wrong way	Check direction of rotation with manufacturer's instructions or direction arrow. On 3-phase motors, direction of rotation may be changed by interchanging any two leads
	Generator or exciter brushes may be loose or missing	Be sure that all brushes bear on the commutator and have proper spring tension
	Exciter may not be operating	Check exciter output voltage with volt-meter or lamp
	Field circuit of generator or exciter may be open	Check for open circuits in rheostat, field leads, and field coils. Also check resistors and rectifiers, if any. Some machines give low output when fields are open
	Generator may be reversed in polarity due to another machine or incorrect operation in parallel with another machine	*Flash the field with a storage battery or another generator, first with one polarity and then with the other, to see if it builds up. (Flash exciter field if set has separate exciter)
	Series field and armature circuit may be open-circuited	Check circuit with ringer or voltmeter
Welding arc is loud and spatters excessively	Current setting may be too high	Check setting and current output with ammeter
	Polarity may be wrong	Check polarity Try reversing polarity or try an electrode of the opposite polarity

*" Flashing " the field of a generator or exciter is a method of establishing the residual magnetism of the field structure with the proper polarity to cause the machine to " build-up," or generate voltage. It consists of passing a relatively heavy current through the field windings momentarily, using an external source of direct current to supply the power.

If a low-voltage source, such as a storage battery, is used, the series field of the generator should be flashed; if a higher voltage source such as another generator or exciter is used, the shunt field should be flashed.

tance and cuts down creeping distances. Some dusts are highly abrasive and actually cut the insulation in being carried through by the ventilating air.

If conditions are extremely severe, weekly inspection and partial cleaning are desirable. Most motors require a complete overhauling and thorough cleaning about once a year.

Transformers.

On fan-cooled arc-welding-transformers of alternating-current welders, fans should be cleaned and lubricated about once a year. Windings should be blown out at least twice a year, more often in dirty places. At the time of this periodic attention, all connections and coil supports should be checked for tightness. Manual current adjusting mechanisms should be lubricated with a fairly high melting-point grease often enough to prevent stiff operation. On motor-operated controls, lubrication at more frequent intervals may be required.

Abuses.

Some not infrequent circumstances cause serious impairment if not complete interruption of the work. One bad practice, for example, is that of leaving weather-protecting tarpaulins thrown over machines in operation, in such a way as to interfere with the free passage of the ventilating air. Sometimes, extension leads for either the electrode or work terminals are not properly connected. It is practically impossible to bolt or wedge untinned flexible cable to another conductor and to secure a good low-resistance joint. Soldered or reliable solderless connectors or terminals should always be used.

The use of excessively long electrode or work leads with motor-generator-type welders will result in overheating of the motor when operating in the upper part of the current range unless extraordinary large cables, or a number connected in parallel, are used. Overheating of the motor from this cause is a frequent reason for motor-generator welders tripping off the line.

A source of trouble which is not protected against by the motor overload relays is the intentional or unintentional application of a long, continued short-circuits on the generator. Because of the low generator voltage involved, the very heavy generator current does not require sufficient power input from the line to cause the motor overload relay to trip. Nevertheless, the generator may be seriously overheated or burnt out.

The use of improperly bonded structural steel systems or building frameworks for the welding-current return circuit is undesirable. The high-resistance path thus afforded to the welding current may result in overheating of the welder motor, and in addition, there is always the possibility that arcing or overheating of some poor connection, possibly quite remote from the scene of operation may start a fire.

No attempt should be made to adjust welding-current output by any means other than those provided and recommended by the manufacturer of the equipment.

In transporting welding equipment, rough handling resulting in permanent mechanical damage is all too frequent. Also care should be taken to avoid using arc-welders out-of-doors in unfavourable weather. Welders, designed to be both semi-protected and drip proof, should not be used in rain or other precipitation without suitable protection. Protecting tarpaulins or temporary shelters must be arranged so as not to hinder ventilation of the equipment.

Common Troubles and their Remedies.

The causes and remedies for the majority of troubles which may occur with arc-welders are given in Table I. However, the proper selection, installation and maintenance of this equipment will serve to reduce these troubles to a minimum.

WELDING TRANSFORMERS AND THEIR CONTROL EQUIPMENT FOR UNIONMELT WELDING

By W. E. WILSON. (From *General Electric Review*, Vol. 45, No. 8, August, 1942, pp. 451-457).

UNIONMELT* welding is a submerged melt welding process in which the welding heat is generated electrically and the operation is carried out automatically. With this process a special Unionmelt welding head and voltage control, supplied by the Line Air Products Company, are used to feed the welding rod into the welding zone and to maintain the proper welding conditions. In addition to these devices, one or more suitably controlled welding transformers are required to supply the heavy current and to operate the welding equipment.

In general, the nominal rating of the transformer (or combined nominal ratings where two or more are operated in parallel) need not be greater than the rating of the head or heads involved, but may be less if sufficient to meet the service requirements; it may be greater, if there is no other transformer available.

The welding heads are made in three standard ratings: 1000-amp., 2000-amp., 4000-amp. The transformer capacity of any of these heads may be obtained either by using a single unit or by using a number of transformers in parallel.

Selection of Transformer Size.

With such freedom in the manner in which the total required transformer capacity can be obtained, the question of size of individual transformer units resolves itself largely into a consideration of the following factors:

(a) Type of transformer mounting—stationary or portable.

(b) Additional uses—the individual transformers may also be used for manual welding when not in use for Unionmelt welding.

(c) Availability—this may also be a factor if a single welding transformer larger than the 1000-amp. unit is considered desirable.

The question of initial investment may seem to favour the installation of multiple units of the 5000-amp. size rather than fewer of the larger units. However, the larger units have about eight per cent higher efficiency and especially those having built-in control require less wiring.

Since the larger transformers having built-in primary control require less space and weight per ampere of installed capacity, they are normally used with portable installations. On the other hand, if the Union melt installation is to be used periodically and if in the meantime the welding transformer capacity could be used for manual welding, then the 500-amp. units might be advantageous.

Open-Circuit Voltage.

In selecting welding transformers for Unionmelt

*Unionmelt is a registered trademark of the Linde Air Products Company.

work or similar applications, any particular open-circuit voltage should not be considered as a requirement of the application. Rather, the open-circuit voltage may be regarded as merely incidental to the particular transformer design.

Insofar as the amount of voltage or current necessary for successful welding is concerned, the most that is required of the welding transformer is sufficient capacity to :

(1) Supply enough welding current to equal the capacity of the head.

(2) Supply this current at a voltage which is high enough to equal the welding voltage plus the voltage drop in any reasonable length of welding cable.

A design which fully meets these requirements of the application and at the same time has an open-circuit voltage of 75 or 80 volts is to be preferred over designs requiring higher open-circuit voltage, because of higher power factor, lower Kva-input, higher safety and saving of operating time as connections do not have to be changed in order to obtain full output.

For these reasons, the welding transformers described in this article embody the integral reactance design which provides full-range output with 80 volts open circuit (Fig. 1) for 750-amp. rating and higher. Equivalent performance is provided by the 500-amp. size having 75 volts open circuit. Designs not employing integral reactance may require higher open-circuit voltages.

Parallel Operation.

When properly connected and operated in parallel, each transformer will deliver the current for which it is adjusted and the total current available for welding will be the sum of the output currents of all units connected in parallel. When operated in parallel, the following precautions should be observed.

The primary side of each unit must be connected to the same phase of the power supply, and must be suitable for the power supply voltage.

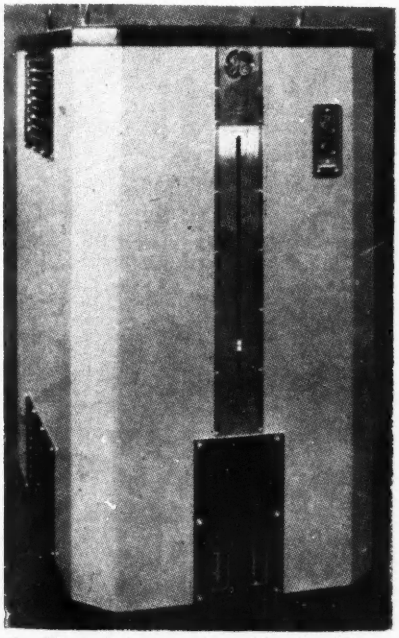


Fig. 1. View of the secondary side of welding transformer showing typical features of 750- and 1000-amp. sites.

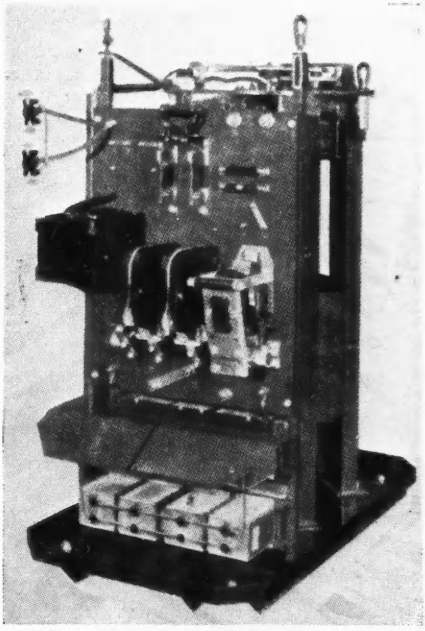


Fig. 2. Primary side of the transformer with door open.

On the output side, the ground and welding terminals must be all properly connected to their respective welding-circuit buses. No special precautions need to be observed relative to differences in open-circuit voltage. Units, having an open-circuit rating of 75 volts could be operated successfully in parallel with sizes having an open-circuit voltage of 80 volts.

A third precaution must be observed when transformers having built-in means of power factor improvement are operated in parallel. When the primary of one of these transformers is disconnected, either its capacitor circuit must be opened or else its secondary circuit must be disconnected from the welding bus. Otherwise, excessive voltage may be built up in het

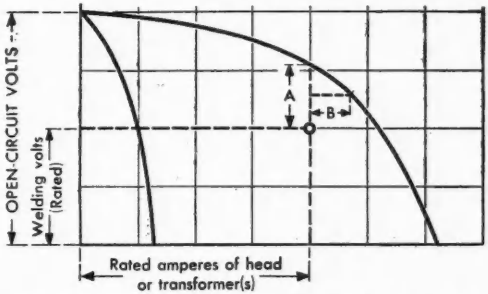


Fig. 3. Transformers embodying the integral reactance principle permit adjustment of their current-regulating reactance over a wide range in proportion to their rating. Hence at rated-current output ample extra voltage (a) is available to compensate for the voltage drop in any reasonable length of welding cable—or if all the extra voltage is not needed, additional current (b) above the rated value can be obtained.

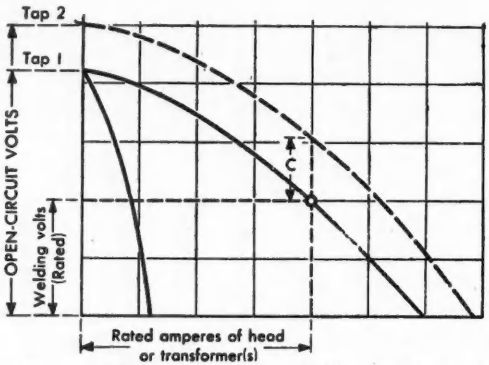


Fig. 4. Transformers not embodying the integral reactance principle, may require an additional tap at higher open-circuit voltage to supply additional voltage (c).

primary winding through resonance with the capactor circuit—a condition which would be hazardous both to operators and to equipment.

Each transformer, having built-in primary control provides a contactor in the capacitor circuit which automatically opens and closes this circuit whenever the line contactor is opened or closed.

The 500-amp. transformators, however, are not made with built-in primary control. To obtain segregated operation, a separate control panel must be installed for each transformer or group of transformers which are to be segregated, the latter being the common practice.

Welding Current Adjuster.

It is desirable that remote control of welding current be provided so that welding current may be changed quickly and easily by means of push buttons mounted on the voltage control panel. For this reason, each unit of the 1000-amp. size is built with motor-operated welding-current adjuster. This feature is also available with the 750- and 500-amp. transformers.

Since the principle function of remote control is to provide only refinement of adjustment at the voltage-control panel, it is not always necessary that each unit of a group be equipped with a motor-operated current adjuster. This arrangement does not reduce the available range, but it does reduce the percentage of the range over which remote control is available.

Built-in Capacitors.

To obtain uniform welding the primary voltage never should change suddenly by more than 5 per cent. Built-in capacitors assist greatly in simplifying the problem of power distribution and of maintaining steady voltage. They boost the power factor from about 50 per cent to over 80 per cent at full load, and increasing up to unity power factor at half load. When operating in the region of unity power factor, loads can be switched on and off a feeder with much less disturbance to voltage than when the power factor is lower.

Capacitors also prevent the flow of practically all the lagging current that would be drawn by transformers not equipped with capacitors. Thus line amperes are reduced which permits smaller primary cable, line switches and fuses to be used.

When the transformers are operated at half load or less, built-in capacitors provide a leading power factor effect which helps to offset any lagging power factor effect caused by motors or other induction loads on the feeder.

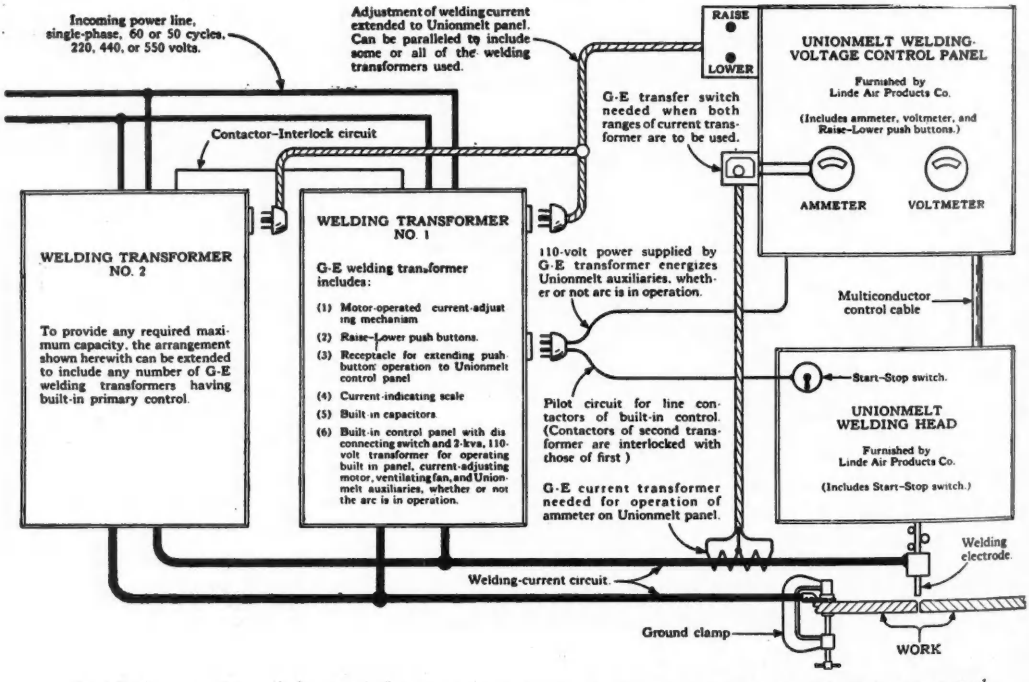

Incoming power line, single-phase, 60 or 50 cycles, 220, 440, or 550 volts.
Adjustment of welding current extended to Unionmelt panel. Can be paralleled to include some or all of the welding transformers used.
RAISE
LOWER
UNIONMELT WELDING-VOLTAGE CONTROL PANEL
Furnished by Linde Air Products Co.
(Includes ammeter, voltmeter, and Raise-Lower push buttons.)
G-E transfer switch needed when both ranges of current transformer are to be used.
Contactor-Interlock circuit
AMMETER
VOLTMETER
WELDING TRANSFORMER NO. 2
To provide any required maximum capacity, the arrangement shown herewith can be extended to include any number of G-E welding transformers having built-in primary control.
WELDING TRANSFORMER NO. 1
G-E welding transformer includes:
(1) Motor-operated current-adjusting mechanism
(2) Raise-Lower push buttons.
(3) Receptacle for extending push button operation to Unionmelt control panel
(4) Current-indicating scale
(5) Built-in capacitors
(6) Built-in control panel with disconnecting switch and 2-kva, 110-volt transformer for operating built-in panel, current-adjusting motor, ventilating fan, and Unionmelt auxiliaries, whether or not the arc is in operation.
110-volt power supplied by G-E transformer energizes Unionmelt auxiliaries, whether or not arc is in operation.
Multiconductor control cable
Start-Stop switch.
Pilot circuit for line contactors of built-in control. (Contactors of second transformer are interlocked with those of first.)
UNIONMELT WELDING HEAD
Furnished by Linde Air Products Co.
(Includes Start-Stop switch.)
G-E current transformer needed for operation of ammeter on Unionmelt panel.
Welding electrode
Welding-current circuit.
Ground clamp
WORK

Fig. 5. Typical arrangement for Unionmelt welding using transformers with built-in primary control.

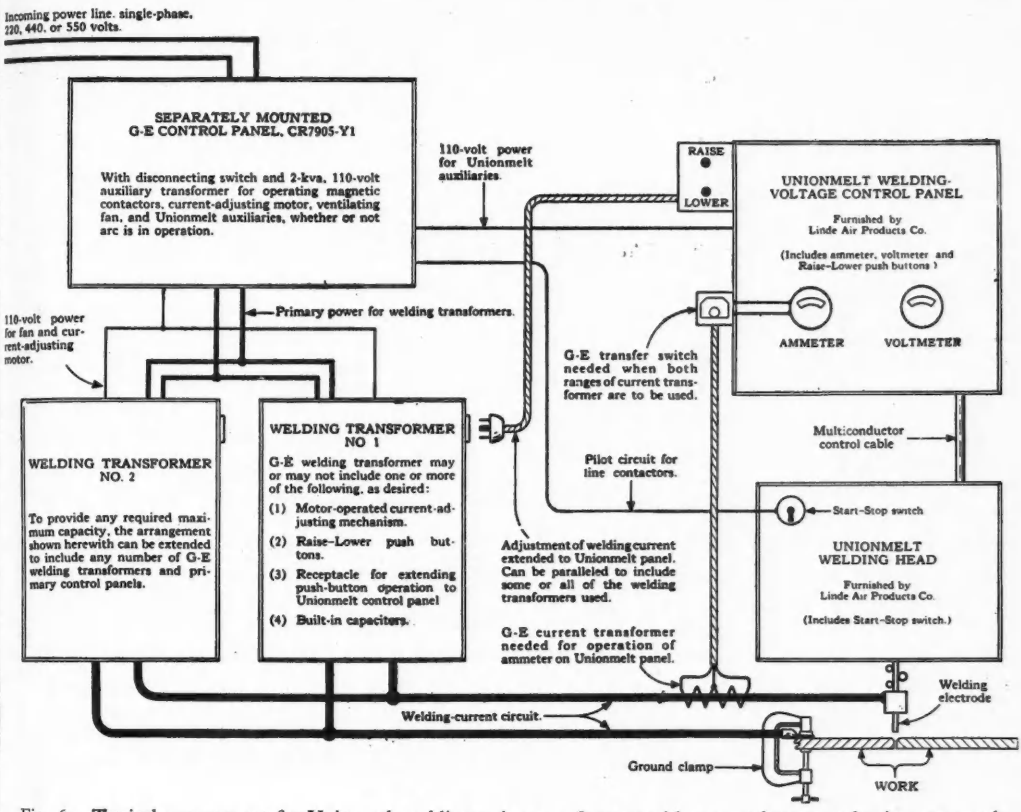

Incoming power line, single-phase, 220, 440, or 550 volts.
SEPARATELY MOUNTED G-E CONTROL PANEL, CR7905-Y1
With disconnecting switch and 2-kva, 110-volt auxiliary transformer for operating magnetic contactors, current-adjusting motor, ventilating fan, and Unionmelt auxiliaries, whether or not arc is in operation.
110-volt power for Unionmelt auxiliaries.
RAISE
LOWER
UNIONMELT WELDING-VOLTAGE CONTROL PANEL
Furnished by Linde Air Products Co.
(Includes ammeter, voltmeter and Raise-Lower push buttons.)
AMMETER
VOLTMETER
Primary power for welding transformers.
110-volt power for fan and current-adjusting motor.
G-E transfer switch needed when both ranges of current transformer are to be used.
Multiconductor control cable
WELDING TRANSFORMER NO. 2
To provide any required maximum capacity, the arrangement shown herewith can be extended to include any number of G-E welding transformers and primary control panels.
WELDING TRANSFORMER NO 1
G-E welding transformer may or may not include one or more of the following, as desired:
(1) Motor-operated current-adjusting mechanism.
(2) Raise-Lower push buttons.
(3) Receptacle for extending push-button operation to Unionmelt control panel
(4) Built-in capacitors.
Pilot circuit for line contactors.
Start-Stop switch
UNIONMELT WELDING HEAD
Furnished by Linde Air Products Co.
(Includes Start-Stop switch.)
Adjustment of welding current extended to Unionmelt panel. Can be paralleled to include some or all of the welding transformers used.
G-E current transformer needed for operation of ammeter on Unionmelt panel.
Welding electrode
Welding-current circuit.
Ground clamp
WORK

Fig. 6. Typical arrangement for Unionmelt welding using transformers with separately mounted primary control.

Built-in Capacitors *vs.* Capacitors on Power Feeder.

A bank of capacitors installed across the power feeder has no corrective effect on the power factor of feeders running from the capacitors to the welding transformers. This requires larger feeder than when transformers with built-in capacitors are used.

Built-in capacitors help to keep the feeder voltage steady because they are automatically switched on and off the line with the welding load. Capacitors connected across the feeder cannot be made to change in proportion to the number of transformers on the line without prohibitive cost.

Built-in capacitors also permit transformers to be moved readily from one feeder to another. In addition they also conserve space because they are included in the transformer case, whereas a bank of capacitors requires extra floor space and extra enclosure.

Selection of Primary Control.

Welding transformers in 750- and 1000-amp. sizes are available with built-in primary control which permits an arrangement illustrated in Fig. 5. Welding transformers of the 500-amp. size do not have built-in control. These as well as alternative designs of the 750- and 1000-amp. units not having built-in primary control must be provided with a separate control panel. This requires an arrangement illustrated in Fig. 6.

Within the limits of its capacity, a transformer with built-in primary control fulfills—as a single unit—the principle requirements for power to operate Unionmelt equipment. Selective operation can be obtained by simply opening the disconnecting switch of any transformer omitted from the operation, because the built-in control isolates the capacitor circuit when not in operation.

Built-in control is especially advantageous for portable application and also simplifies wiring, as illustrated by a comparison between Figs. 5 and 6.

With either type of primary control, however, an auxiliary transformer with a rated output of 2 kva, 110/220 volts and protected by fuses is included to furnish power for operating the current-adjusting motor and the transformer and Unionmelt auxiliaries. A disconnecting switch permits quick, easy removal of all power from the control panel and the transformer.

Provision for Metering.

A voltmeter and ammeter are furnished with the Unionmelt welding voltage-control panel as standard equipment. The voltmeter is so connected as to indicate welding voltage. A voltmeter located on the welding transformer would not indicate arc voltage, but instead the sum total of arc voltage plus the resistance and reactance voltage drops in the welding secondary cables.

The ammeter on the Unionmelt panel is placed there for the purpose of indicating welding current. Since its current transformer is installed on the main welding bus, it causes the ammeter to indicate total welding current regardless of the number of welding transformers which may be used in parallel to make up this current.

The current indicators on the side of each welding transformer are of sufficient accuracy to indicate the division of load between the transformers. However, a separate ammeter can be installed on each welding transformer, terminals being already provided for making the electrical connections. The primary rating of the current transformer on the Unionmelt panel should at least equal the rating of the welding head with which it is used.

DRAG PROBLEMS IN PRESENT DAY AIRCRAFT DESIGN

By DIPL. ING. WERNER HAUSAMMANN, Eidgenoessische Konstruktionswerkstaetten, Thun, Switzerland.
From *Flugwehr und Technik*, Vol. IV., No. 7, July, 1942. pp. 179-184.

THE development of aircraft during the past twenty years has brought about a tremendous increase in speed. Prototypes of to-day have a speed of 760 km/h (470 m/h) and it is expected to reach 850 km/h (530 m/h) in level flight in the near future.

Principally the following possibilities exist to improve aircraft performance :

1. Increasing engine power, reducing weight-power ratio, fuel consumption and frontal area.
2. Reducing the structural weight through more exact estimation of the forces acting; new materials.
3. Aerodynamic improvements by
   (*a*) reduction of all dimensions to the absolute minimum necessary (high wing loading, small frontal areas and small surface areas).
   (*b*) avoiding sources of drag, reduction in magnitude of the unavoidable drag. (Reduction of friction drag by improvement of surface finish).
   (*c*) increase in airscrew efficiency.

Especially points 3 *a* and *b* are promising for future development. In addition to the above mentioned requirements at speeds beyond 650 km/h (400 m/h) the compressibility of air has to be taken into account.

The total drag of a modern aircraft with the maximum speed of about 600 km/h (370 m/h) can be subdivided as follows :

Wing	Friction drag	36 %	44 %
	Form drag	3 %	
	Induced drag	5 %	
Fuselage	Friction drag	21 %	31 %
	Form drag	10 %	
Tail unit	Friction drag	4 %	8 %
	Form drag	4 %	
	Cooling drag	9.5 %	17 %
	Ventilation drag	2 %	
	Interference drag	5.5 %	
	Total		100 %

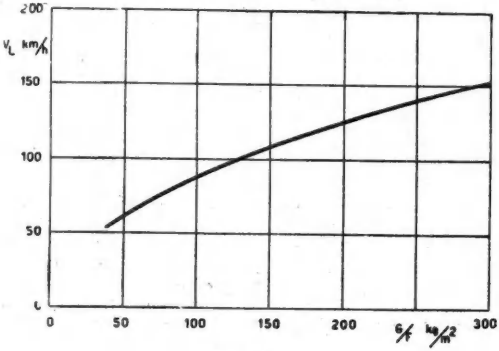


Fig. 1

It can be seen that frictional drag amounts tc 61 % of the total drag.

The wing loading, an active means for speed increase has risen from 40 kg/m² (8.2 lb./sq. ft.) of 25 years ago to the present value of 200 kg/m² (41 lb/sq. ft.) and beyond. The possible increase in wing loading is limited by the simultaneous increase in induced drag which tends to counterbalance the gain in profile drag due to the higher wing loading.

In the above example the induced drag was 5 % of the total drag. When climbing at a speed of 60 % of the maximum speed, 15 % of the engine power is absorbed in overcoming the induced drag.

Another difficulty of high wing loading lies in the high maximum lift coefficient for landing. Fig. 1 shows the relation between wing loading G/F and landing speed V_L. The diagram is made for 500 metres, I.C.A.N. conditions.

It has been shown above that the greatest percentage of total drag consist of friction drag. The subdivision of drag into friction drag and form drag of a body is somewhat uncertain as the friction drag is dependent also on the shape of the body. It is better to replace " form " drag by the term " pressure " drag, as one can understand by this the component in the direction of flow of the pressure exerted by the flow on the body (see Fig. 2).

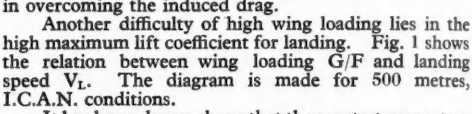


Fig. 2

Thus, the pressure drag W_D is :

$$W_D = \int p \cdot \sin \varphi \cdot df$$

The friction drag W_D can be defined as a component in the direction of flow of the frictional forces acting on the surface.

$$W_R = \int \tau_0 \cdot \cos \varphi \cdot df$$

The total resistance $W_{tot} = W_D + W_R$.

The pressure distribution thus determines the pressure drag. For high-speed flying, therefore, the lift will not be governed by the angle of incidence but by cambering of the profile, because the pressure at zero incidence is very small.

The immense influence of the laminar and turbulent boundary layer on the friction drag is well known. Fig. 3 gives the friction drag coefficient as a function of the Reynolds number. Laminar flow according to Blasius is denoted by a ; the turbulent flow according to Kármán by b. Whether laminar or turbulent boundary layers are obtained round a body, depends on the flow and other factors. Generally, in the front part the boundary layer is laminar, then there is a zone of transition in which turbulence starts. In Fig. 4, a is the

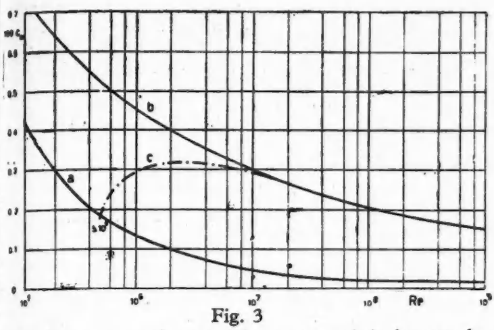


Fig. 3

laminar zone, c the transition zone, and, b denotes the fully turbulent zone which, however, has a laminar sub-layer d.

The transition curve in Fig. 3 is shown too, and denoted by c. The transition point is at Reynolds number, Re = 5×10^5.

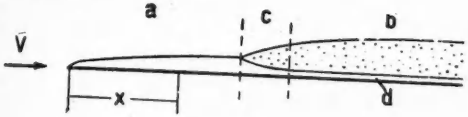


Fig 4

With increasing Reynolds number as well as with increasing degree of turbulence, the transition point moves forward. This results in an increase in drag ; a greater percentage of the boundary layer being turbulent. It is as yet impossible to state for a flat plate a simple relation between Reynolds number of the transition point and the degree of the turbulence of the air. The reason being the complex nature of turbulence. It is of great significance for aviation that the degree of turbulence of the free atmosphere is small as compared with that of wind-tunnels.

Influence of surface roughness.

(*a*) Laminar boundary layer : A permissible roughness exists here, below which the local roughness has no influence on the transition point or drag coefficient C_W. The surface can be regarded as smooth. As soon as a permissible roughness is exceeded, the transition point moves forward. Between the value $\sqrt{\frac{\tau_0}{\rho}}$ and the permissible roughness the following relation has been established experimentally[1] :

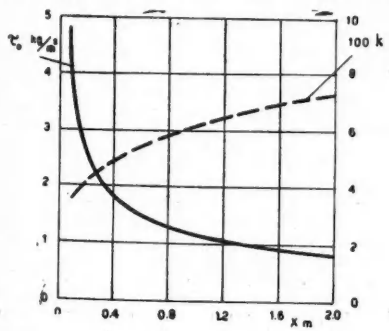


Fig. 5

$$\frac{k \cdot \sqrt{\frac{\tau_0}{\rho}}}{\nu} = K$$

ν = kinematic viscosity of air.
τ_0 = local shearing stress.
ρ = density of air.
K = permissible roughness.

The constant K found by experiment is :

K = 13 for the flat plate.
K $\simeq$ 13 to 16 for aerofoil sections.

$\sqrt{\frac{\tau_0}{\rho}}$ is a function of the location and the shape of the body, and can be found by Polhausen's method within the zone of a negative pressure gradient.

In Fig. 5 τ_0 and K for the flat plate are plotted against, x, the distance from the leading edge, at a speed of flow V = 180 m/sec. at zero height, I.C.A.N. conditions. It can be seen that the requirements as to roughness are not severe in the laminar boundary layer. The grain size of 0.025 mm obtained by sprayed dopes is sufficient and the front part need to be polished only, as K is here low.

(*b*) Turbulent boundary layer : in Fig. 6 the coefficient of friction C_W of the flat plate is plotted against Reynolds number. The roughness K is divided by t, the wing chord as parameter. (For completeness the laminar flow is shown dotted, the transition dash-dotted). The curves show that the smaller the relative roughness, the higher the Reynolds number up to which the plate can be regarded as if it was perfectly smooth.

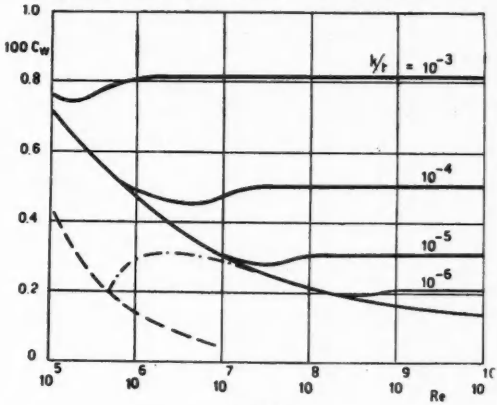


Fig. 6

This behaviour has its physical explanation in the fact that local break-away occurs as soon as a grain protrudes from the laminar sub-layer. The roughness has less effect toward the trailing edge as the thickness of the laminar sub-layer is there increasing. The graph in Fig. 6 has been obtained experimentally. The following empirical relation has been found for the permissible roughness :

$$\frac{V \cdot k}{\nu} < 75 \text{ to } 110 \text{ for } R_e = 7 \cdot 5 \times 10^4 \text{ to } 1 \cdot 1 \times 10^8$$

As an example, for the flat plate at V = 180 m/sec., the permissible roughness k $\simeq$ 0.008 mm. Such a smooth surface can be achieved only by the most careful treatment. The surface roughness of present-day aircraft, increases the profile drag by 13-14 % as compared with the perfectly smooth wing.

(1) Tani, Hama and Mituisi : On the Permissible Roughness in the Boundary Laver. Report of the Aeron. Research Institute, Tokio, No. 199, October, 1940.

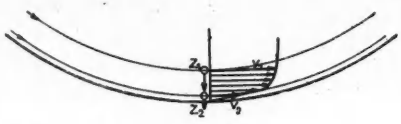


Fig. 7

Influence of the pressure gradient.

Positive pressure gradients tend to bring about transition, negative pressure gradients delay it. This can be exemplified by the flat plate.

If Re_x is the Reynolds number of the transition point, $Re_x = 1.1 \times 10^6$ for zero pressure gradient, $Re_x = 1.8 \times 10^6$ for pressure gradient from leading edge to transition point equal to -5% of the stagnation pressure.

The pressure gradient influences the local laminar and turbulent friction, whereby the positive gradient diminishes the coefficient C_W, the negative increases C_W. The reason for this is, that the thickness of the boundary layer increases with positive gradient, thereby the velocity gradient at the surface becomes smaller and thus the shearing stresses become smaller, too. The laminar boundary layer tends to break away rather more than the turbulent layer. The latter is capable of overcoming considerable pressure increases.

Influence of curvature.

Convex curvature of surface delays transition, concave curvature accelerates it. For instance, for a radius of curvature of 50 cm, the Reynolds numbers of transition are given by

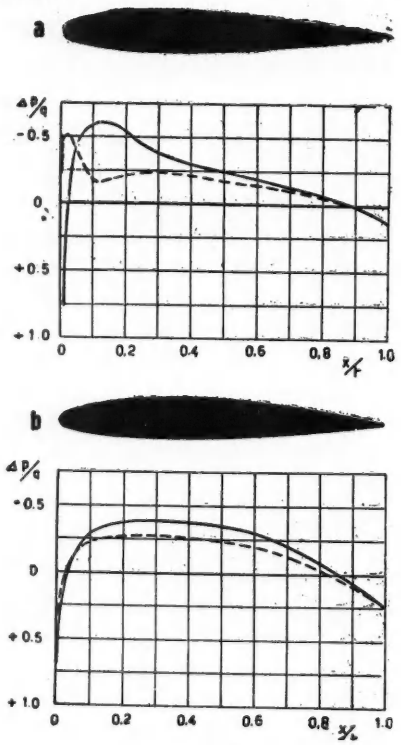


Fig. 8

Re convex = 2 Re concave (2).

The explanation of this lies in the centrifugal effect of the curved flow. For the concave curvature in Fig. 7 one can see that the particles at the proximity of the surface are more strongly braked than those at some distance within the boundary layer. This results in $V_1 > V_2$ and thus the centrifugal forces are $Z_1 > Z_2$. However, this state is unstable and the resulting lateral movements increase the turbulence and movement of the transition point occurs.

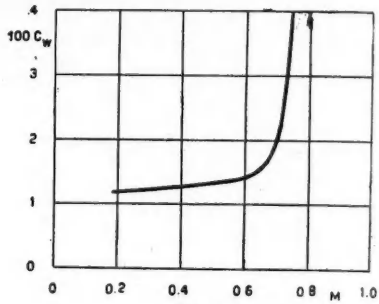


Fig. 9

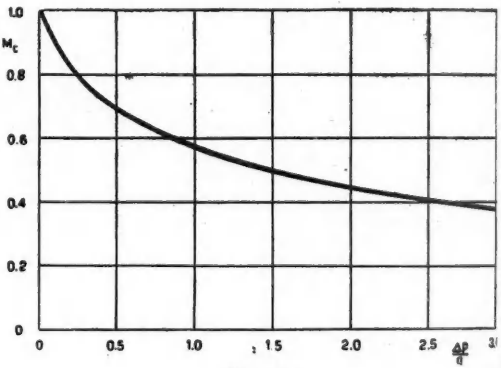


Fig. 10

Based on the above mentioned phenomena, aerofoil sections have been designed which excel by having a large region of laminar flow. A typical representative of this high-speed aerofoil is shown in Fig. 8b. Both sections, Fig. 8a and b, have their maximum thickness equal to 12% of the chord t, and the diagrams give the pressure distribution for Ca = 0.08. Fig. 8a shows the NACA 23012 aerofoil, Fig. 8b a high-speed section, measured in the wind-tunnel of the E.T.H.(3). The full curve gives the pressure distribution over the upper side, the dotted curve over the lower side.

Considering that the transition point must lie near the mimimum pressure point, it can be seen that with a high-speed aerofoil the percentage of laminar flow is considerably greater and thus the drag is smaller.

Moreover it can be seen from the pressure distribution that super-speeds are smaller with the high-speed aerofoil than with the usual one. This has a favourable influence on the compressibility effect. It is well known that at high speeds the compressibility

(2) Clause: The effect of curvature on the transition from laminar to turbulent Boundary Layer. NACA, Techn. Notes, No. 613, September, 1937.

(3) E.T.H. being the abbreviation for Eidgenoessische Technische Hochschule, the Swiss Federal Technical College of Zurich. —Editor *Engineers' Digest.*

effect of the air changes the characteristics of flow, and that the relevant figure for the occurrence of this change is Mach's number M :

$$M = \frac{V}{a} = \frac{\text{speed of flow}}{\text{speed of sound}} \quad (4)$$

Fig. 9 shows the increase of the drag coefficient C_W with M for the NACA 4412 aerofoil at $Ca = 0.2$. With this drag increase occurs a sudden drop in lift. The maximum suction for compressible flow can be found by using the relation of Prandtl and Glauert for the incompressible flow.

The notation being :

$\left(\frac{\Delta p}{q}\right)$ = pressure coefficient.

Δp = pressure difference.

$q = \frac{\rho}{2} V^2$ = stagnation pressure.

Suffix O : incompressible flow.

Suffix M : compressible flow at Mach number M (related to the undisturbed flow).

Then: $$\left(\frac{\Delta p}{q}\right)_M = \left(\frac{\Delta p}{q}\right)_o \cdot \frac{1}{\sqrt{1-M^2}}$$

More accurate is the expression by Kármán-Tsien.

$$\left(\frac{\Delta p}{q}\right)_M = \left(\frac{\Delta p}{q}\right)_o \frac{1}{\sqrt{1-M^2} + \frac{M^2}{1+\sqrt{1-M^2}} \left(\frac{\Delta p}{q}\right)_o}$$

To each value of $\frac{\Delta p}{q}$ there is a critical Mach number M_c, at which the speed of sound is reached. Fig. 10 shows $Mc = f\left(\frac{\Delta p}{q}\right)$

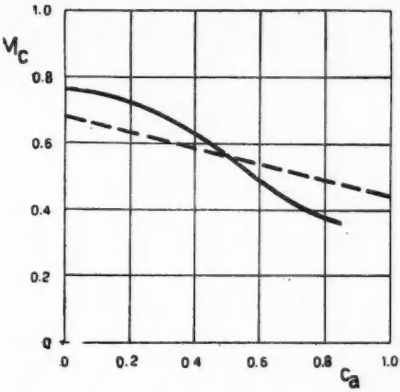


Fig. 11

To avoid shock stalling the super-speeds must be reached as far as possible. In fulfilling this requirement for aerofoils, the shape realised is identical to that obtained for large percentage laminar flow, i.e. the high speed aerofoil.

In Fig. 11 the critical Mach number is shown as a function of the lift coefficient C_a. Both curves are for aerofoils of a maximum thickness equal to 12% of the chord ; the dotted curve applies to NACA 23012, the full curve to the high-speed aerofoil.

Especial attention must be paid to the design of airscrews as the compressibility effect is greatest here. Analogous conditions are encountered at the wing-fuselage joint, nacelles, slots, etc.

(4) The problem of Compressibility has been dealt with in Flugwehr und Technik in an article by Professor Ackeret the head of the Aerodynamics Department of the E.T.H. We consider this article to be of general interest, and shall abstract it therefore, for the benefit of our readers in future numbers of *The Engineers' Digest*. Editor.

THE TORSIONAL FATIGUE STRENGTH OF HIGH TENSION STEEL

By H. CORNELIUS and F. BOLLENRATH, Report of the Research Institute for Material Testing, D.V.L., Berlin-Adlershof. (From *V.D.I.-Zeitschrift*, Vol. 86, No. 7/8, 21st February, 1942, pp. 103-108).

THE most important application of high tensile steels is in aero-engine crank-shafts. In Germany the strength limits are 90 to 100, and 120 to 130 kg/mm². As some captured engines have shown, the same limits apply abroad too (i.e., England, France and U.S.A.).

Some years ago crankshafts were used, the ultimate tensile strength of which by far exceeded 130kg/mm². Modern aero-engine design tends again towards such high values. As the machining of high tensile steels is both difficult and expensive, the employment of steels over 130kg/mm² offers advantages only if the torsional fatigue strength increases simultaneously.

The relationship between tensile strength and torsional fatigue strength is shown in Fig. 1-3. The results were obtained by E. Houdremont.* As information on the torsional fatigue strength is scanty and for higher tensile values it seems to be lacking entirely, the author carried out experiments on two steels, the compositions of which are given in Table I.

Both whole and cross drilled cylindrical test pieces were used as shown in Fig 4 and 5. (All dimensions in millimeters). The surface of the testpieces was ground and polished with 000- abrasive. The ultimate tensile stress was varied by a suitable heat treatment. To obtain an ultimate tensile stress of 170 kg/mm², the test pieces of material B have been quenched in water at 860° C and tempered at 120° C. For the lower carbon steel, A, the corresponding treatment (using a quenching temperature of 820° C) yields an ultimate tensile strength of 160kg/mm².

Table 2 contains data derived from static tests, and

*See : Stahl und Eisen, Vol. 59, 1939, pp. 1-8 and 33-39.

TABLE I.

Steel	Constituents in %									
	C	Si	Mn	P	S	Cr	Ni	Mo	W	V
A	0.22	0.32	0.42	0.01	0.01	1.66	4.2	—	0.98	—
B	0.32	0.44	0.63	0.012	0.01	2.47	1.5	0.29	—	0.30

TABLE II.

Steel	Specified Strength Limits	Proof Stress		Ultimate Tensile Strength	Elongation	Reduction in Area	Notched bar impact test
		$\sigma_{0.02}$	$\sigma_{0.2}$	σ_B	δ_{10}	Ψ	
	kg/mm²	kg/mm²	kg/mm²	kg/mm²	%	%	kgm/cm²
A_1	90 to 100	—	79	95	21	71	—
A_2	120 to 130	—	114	130	15	54	—
A_3	140 to 150	97	121	144	9	60	11,4
A_4	160 to 170	93	128	160	8	56	10,1
B_1	90 to 100	—	87	99	18	67	—
B_2	120 to 130	—	124	131	12	50	—
B_3	140 to 150	104	129	155	8	55	7,8
B_4	160 to 170	100	133	170	7	49	9,0

in addition the notched bar toughness of the test samples.

In the following, the nominal torsional stresses τ_w refer to the undrilled sample, whilst τ_{nw} is associated with the effective cross-section of the drilled sample.

Results in the torsional fatigue tests are shown in Fig. 6. σ_B denotes the tensile stress. For both steels, the torsional fatigue strength of the undrilled sample increases as the ultimate tensile strength is raised up to 130kg/mm². Further increase in tensile strength from 130 to 170 kg/mm² causes a reduction of the torsional fatigue strength.

The drilled sample on the other hand showed a continuous increase in fatigue strength over the whole range up to 170kg/mm². It is remarkable, that for the highest tensile strength, the fatigue strength of the drilled and undrilled samples is the same, i.e., the notch effect of the cross bore is not greater than that due to surface defects in the undrilled sample.

An examination of the fractures on undrilled test-pieces of steels A and B (Figs. 7 and 8) reveals that with increasing ultimate tensile stress the τ_w- values of Fig. 6 correspond less and less to the ideal fatigue strength.

Fig. 9 shows the fracture of a cross-bored sample of steel 'A' of an ultimate tensile strength of 140-150 kg/mm², where the rupture started from a surface defect due to polishing.

Fig. 10 shows a typical torsional fatigue fracture

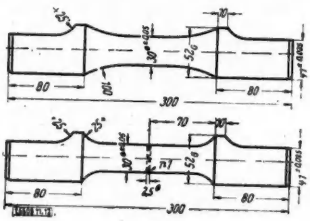


Fig. 4

Fig. 5

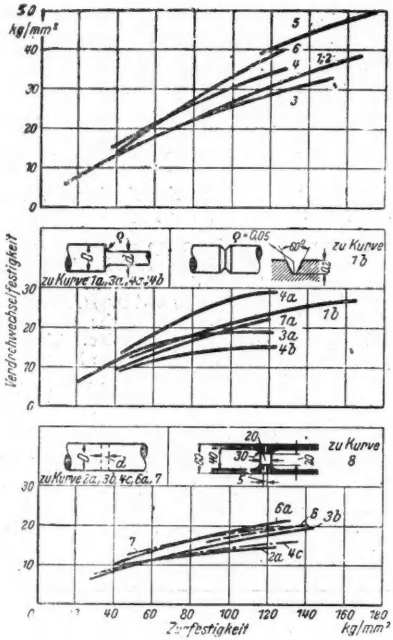


Fig. 1, 2 and 3

(Verdrehwechselfestigkeit = Torsional fatigue strength ; Zugfestigkeit = Tensile strength ; zu Kurve = to curve).

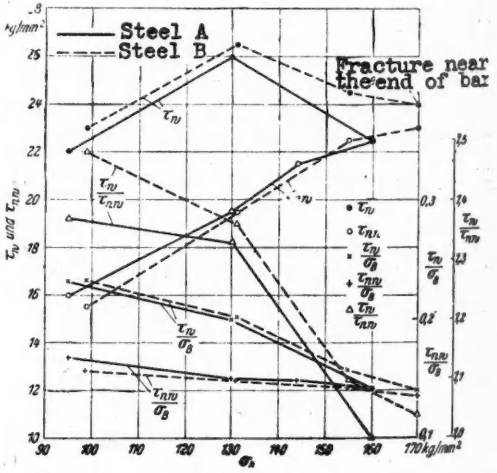


Fig. 6

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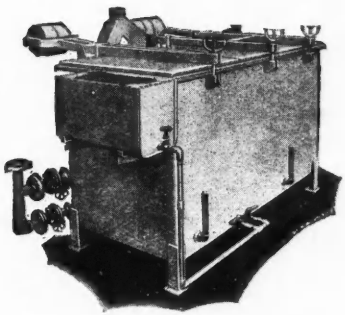

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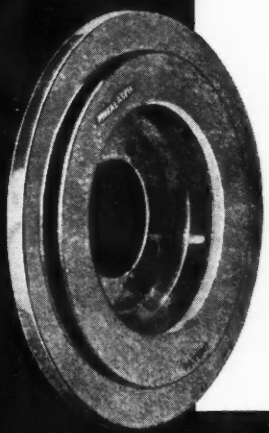

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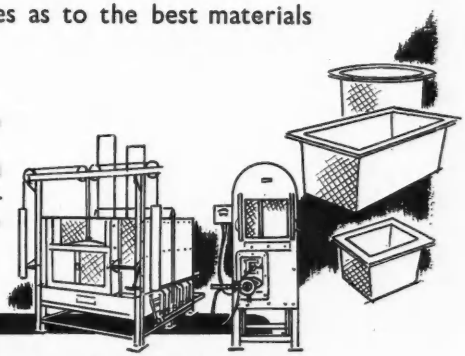

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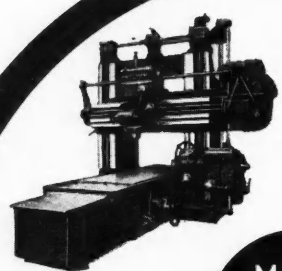

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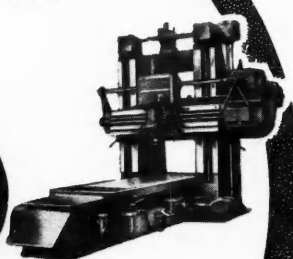

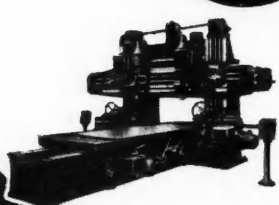

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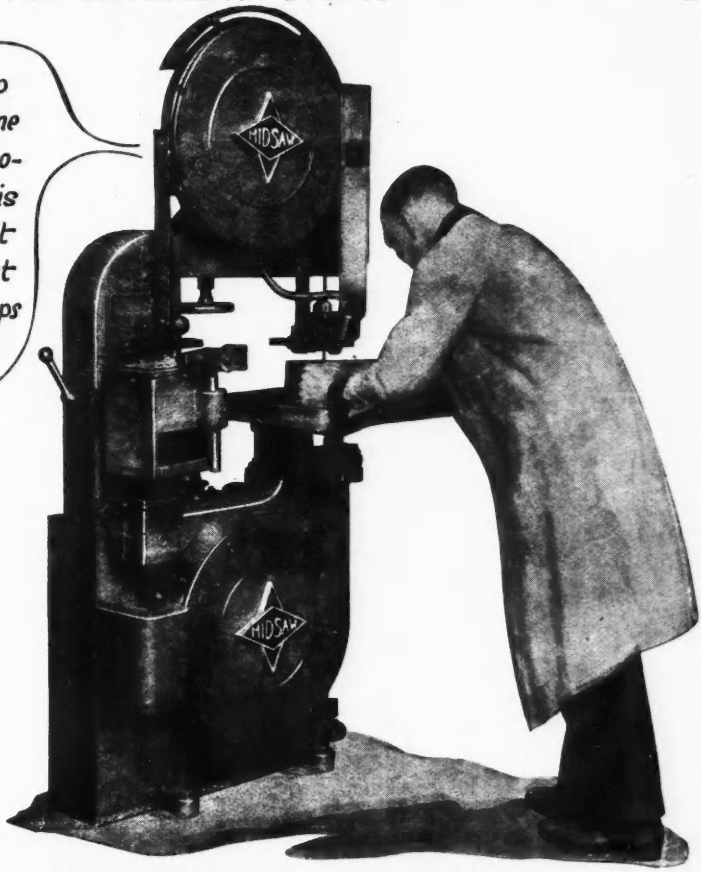

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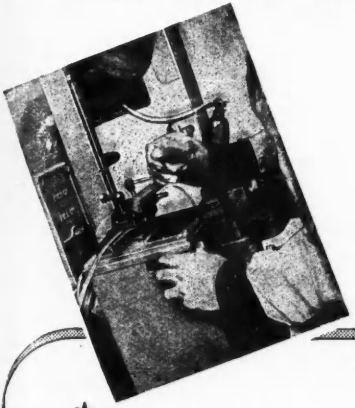

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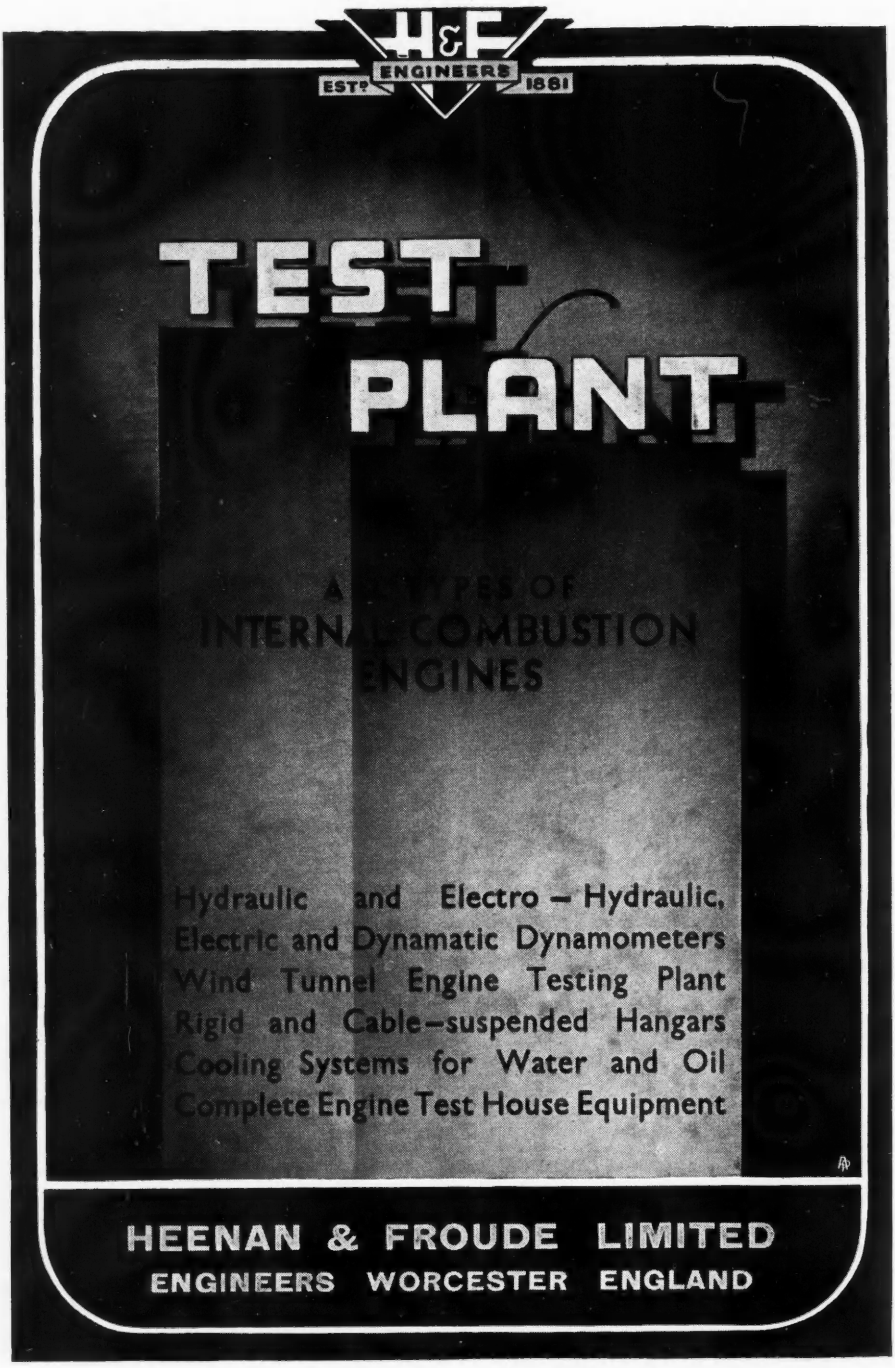
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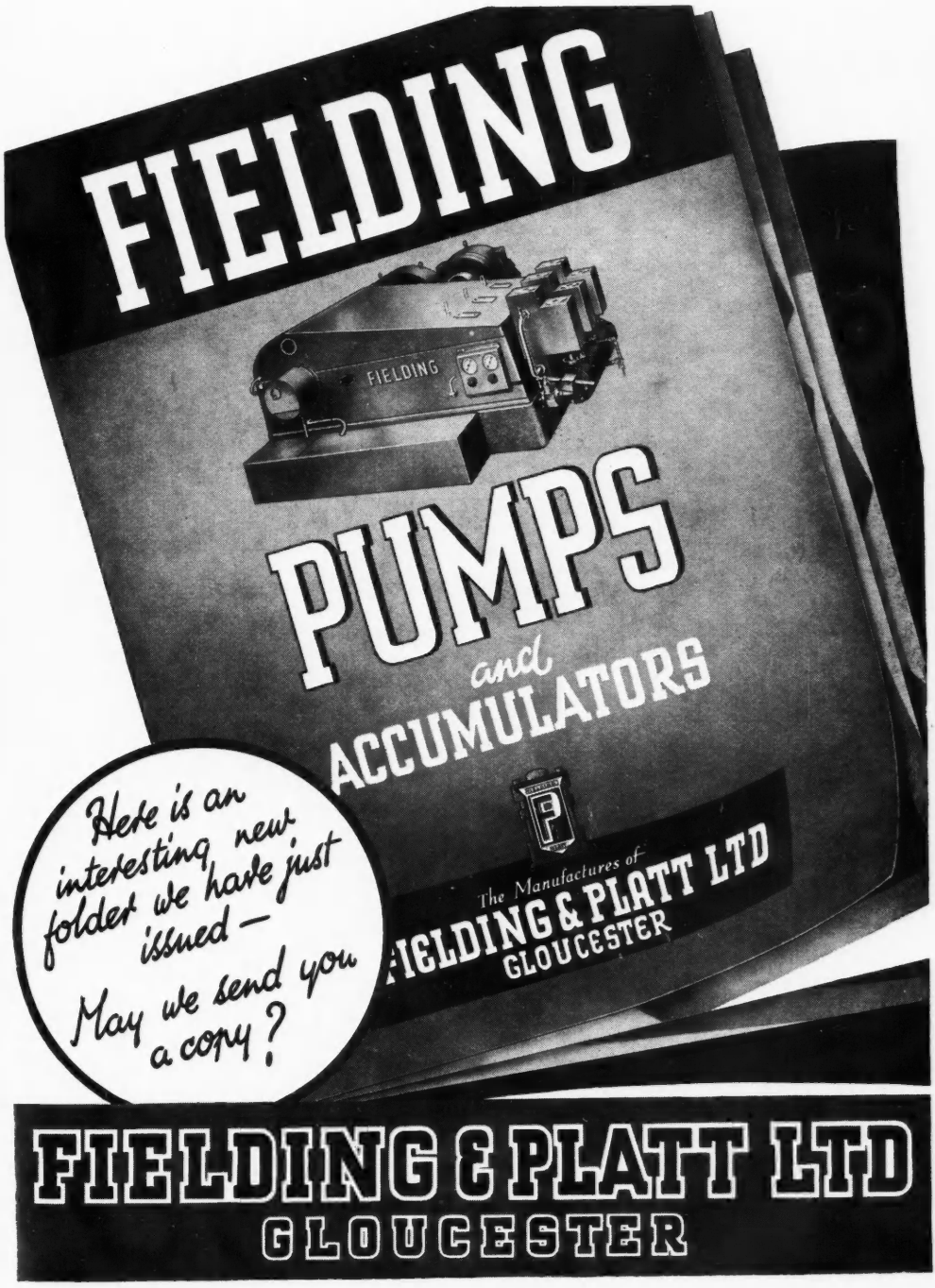
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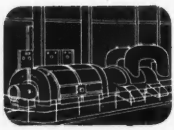
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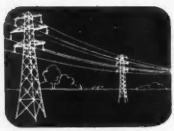
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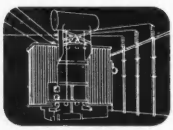
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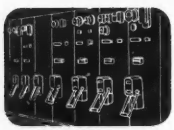
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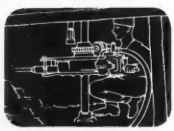
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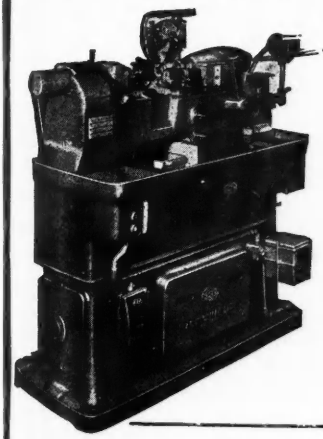

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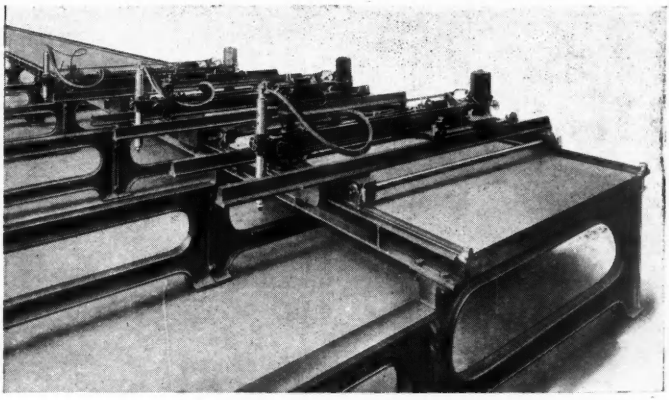

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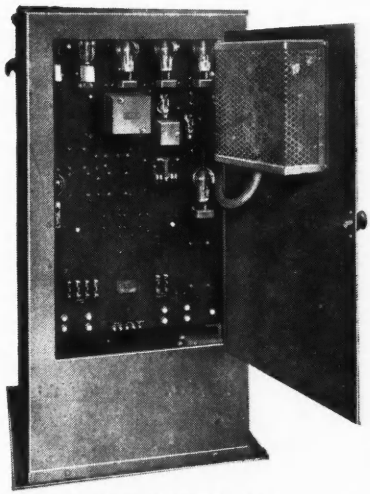

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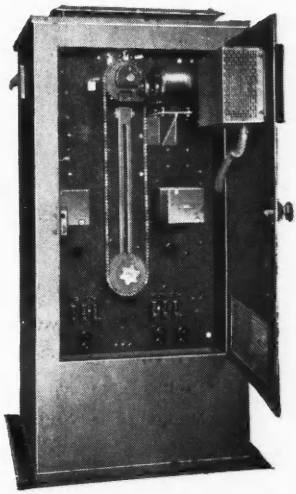

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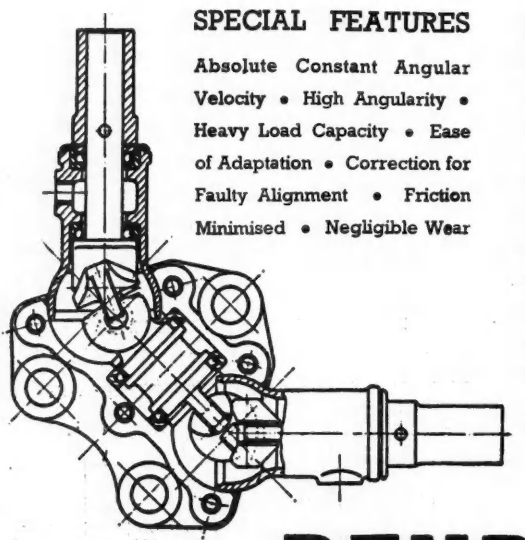

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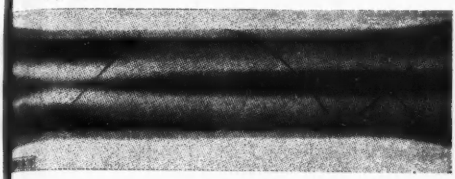


Fig. 7

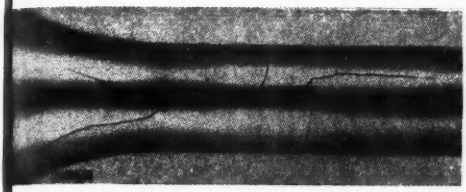


Fig. 8

Fig. 9

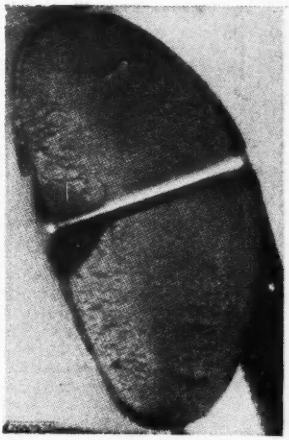


Fig. 10

initiated by the cross-bore. The material is steel 'B' with an ultimate tensile stress of 160-170kg/mm². Fig. 9 and 10 should serve to illustrate two cases of the many tested which lead to the conclusion that with high-tensile steels the notch effect of surface defects is of equal order to that due to the cross-bore.

From the above the conclusion can be drawn that ultra high tensile steels can be of advantage for crank-shafts, provided that a very high degree of surface finish of the shaft can be assured.

THE MOST EFFICIENT LAY-OUT OF ELECTRIC ARC FURNACE STEELWORKS.

By HEINRICH MUELLER. (From *Stahl und Eisen*, Vol. 61, No. 29, July, 1941, pp. 685-694).

ARC-FURNACES have been employed mostly in existing steelworks equipped with open-hearth Siemens-Martin furnaces, or in extensions of such plants. Even new electric-arc steelworks are planned on the same lines as open-hearth plants, i.e., with 2 bays, each equipped with travelling cranes. This arrangement leads to certain difficulties, which so far have been overcome only partially or at the cost of complications and additional expenses for auxiliary installations.

Arc-furnaces are frequently placed in the so-called furnace bay, the individual furnaces being perpendicular to the crane runways. With this arrangement they must have long spouts to bring the liquid steel underneath the central crane runways in the foundry bay; long spouts on the other hand constitute a definite disadvantage from the metallurgical point of view. For top-charged furnaces, the electrode supports and the furnace superstructure must not interfere with the cables of the foundry crane when tilting the furnace, and this condition, too, demands the use of long spouts.

(*To be continued*).

Fig. 1
Older type arc furnace with long spout; placed in the furnace bay.

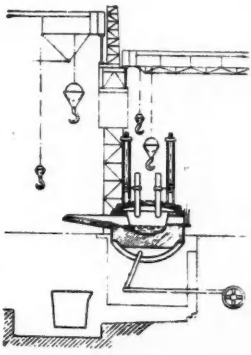


Fig. 2
Chute-charged furnace placed in the foundry bay.

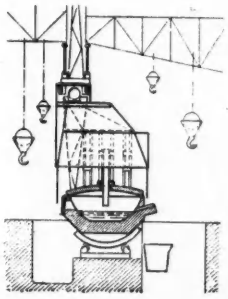
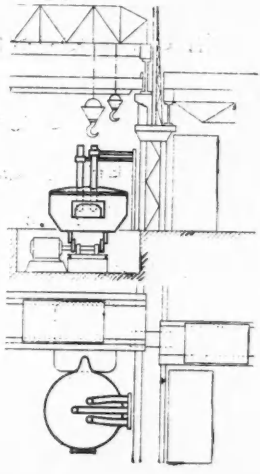


Fig. 3
Furnace placed perpendicular to the crane runways.



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TECHNICAL NEWS

Announcements in this section include News relating to British Firms, and on Equipment produced by British Manufacturers.

Available literature may be secured by addressing a request to the advertising department of "The Engineers' Digest," or by writing direct to the manufacturer and mentioning "The Engineers' Digest" as a source.

- NEW EQUIPMENT
- BOOKS AND CATALOGUES
- BUSINESS CHANGES
- PERSONAL
- NOTES

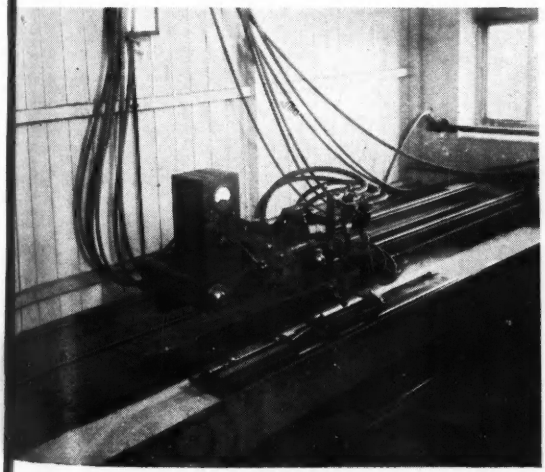
NEW EQUIPMENT

SHORTER G.6 BLADE HARDENING MACHINE.

THE illustration shows the Shorter G.6 blade hardening machine which can be used for longitudinal surfaces, such as machine tool beds, straight edges, blades and multi parts fitted into jigs and general straight line work. It is built on the lines of a machine tool similar to the standard Shorter G.2 gear hardening machine but has a longitudinal track of any required length.

It is driven with a Ward Leonard Set, with bus-bars at the back of the machine and contactors fitted to the machine head. The control panel includes a speed indicator. Automatic equipment for intermittent hardening can also be provided; repetition parts can be laid in the long tank upon jigs so that the work can be progressing as the operator is removing other parts already treated by the machine. Multi burners with multi jets on burner carriers are employed to cover any required width of face or number of faces to be treated simultaneously.

The Ward Leonard Set consists of a main driving motor connected to the public electricity supply. This motor drives a generator and also a small field exciter. All three machines are coupled together by means of flexible couplings and are mounted on a common base plate. This Ward Leonard Set Generator supplies current to the geared variable speed drive motor on the machine head. The method of obtaining the variable speed of this geared motor is as follows :—



The exciter supplies current at a constant voltage to the field of the geared variable speed motor. Current for the generator field is also supplied by the exciter but in this case the current flowing through the generator field can be varied by means of the potentiometer provided on the machine head control-panel. Thus the strength of the generator field can be varied at will between very wide limits. This means that the output voltage of the generator can also be varied over a wide range. Since all other conditions remain unaltered the speed of the geared drive motor is solely dependent upon the voltage of the current applied to its armature. The speed of the machine head is shown by a voltmeter calibrated in inches per minute, which is connected in parallel across the generator armature. It will be seen that the speed of the variable speed geared motor is entirely independent of the load, any increase in load merely causing the motor to take more current from the generator.

Therefore, once the speed of the machine head has been adjusted to suit the job, no variation of the speed

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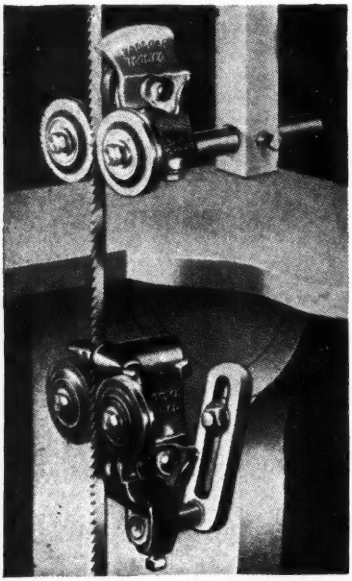
can take place ; this ensures that the correct depth of hardness is maintained throughout the whole length of the traverse.

The speed of the machine head between the limits of 1.4 to 14 inches per minute, can be obtained by this arrangement. The Ward Leonard Set is placed in a convenient position on the floor and a pilot switch controlling the contactor type starter is fitted in the control-panel to enable the Ward Leonard Set to be shut down conveniently when not required.

The control-panel is also provided with a reversing switch to enable the machine head to be traversed in either direction.

BAND SAW GUIDE.

THE Freeman Supply Co., 1152, East Broadway, Toledo, O., has announced an improved type ball bearing band saw guide applicable to saws cutting



practically any material. In the foundry it is claimed the guide permits close operation of the saw and consequent reduction in grinding time on the castings. The fire hazard is reduced while sawing gates from magnesium castings even when the saw is running at high speed. Time is saved in the pattern shop where the guide support enables the operator to work rapidly and accurately. Blade breaking is claimed to be eliminated through use of the guide.

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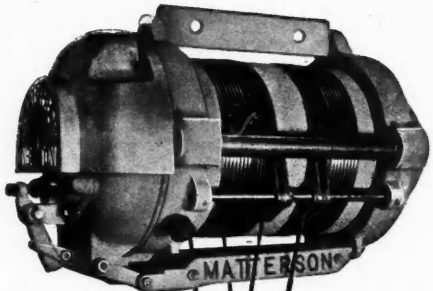

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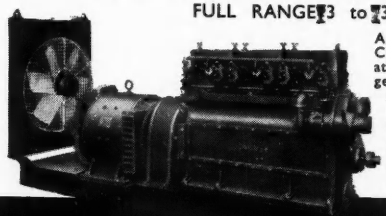

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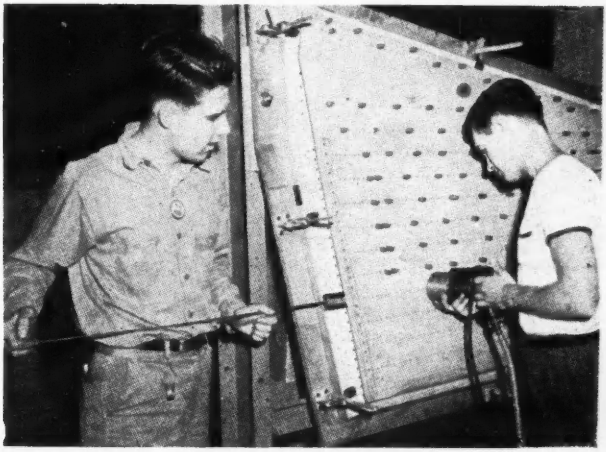

EDITORIAL INDEX

The **Editorial Index** to Vol. III., January-ember, 1942, will be sent to all subscribers free of rge, together with the January, 1943, issue. Binding es for the binding of Vol. III. are now available. e price is 4/6 including postage.

PERSONAL

Mr. C. E. Fairburn has been appointed Chief Mechanical Engineer to the L.M.S. in the absence of Mr. W. A. Stanier who has been seconded to the Ministry of Production on special duties. Mr. Fairburn's headquarters will be at Nelson St., Derby.

Mr. Cecil Bentham, M.Inst.C.E., M.I.Mech.E., has been elected President of the British Engineers' Association for the ensuing year.

Mr. J. Ramsay Gebbie, B.Sc., has been elected President of the North-East Coast Institution of Engineers and Shipbuilders.

Mr. Cecil Kimber, M.I.A.E., has been appointed Works Director to Specialloid Ltd.

Mr. R. L. Brown has been appointed Chairman of Directors of Hopkinsons Ltd., Huddersfield.

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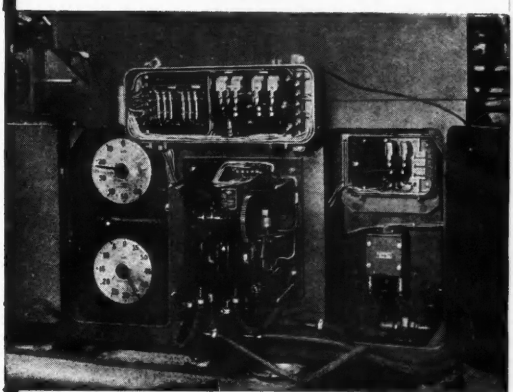

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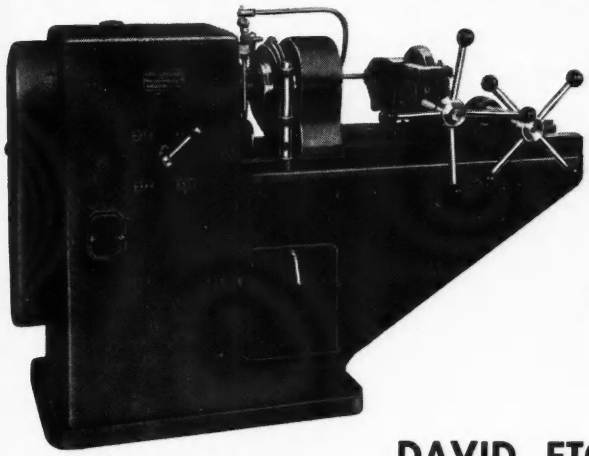

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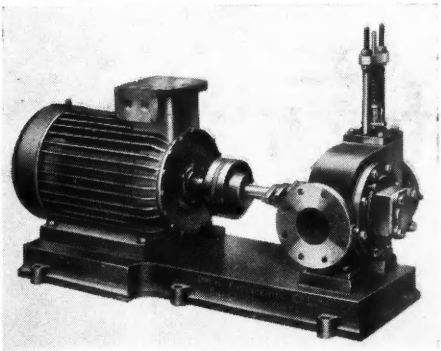

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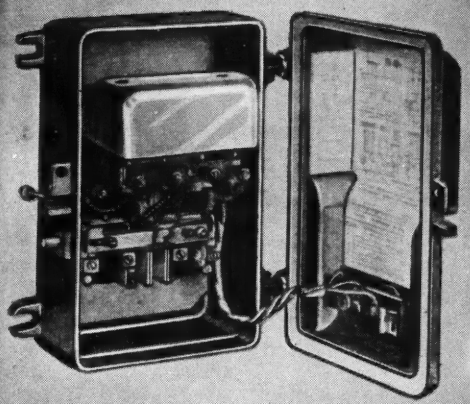

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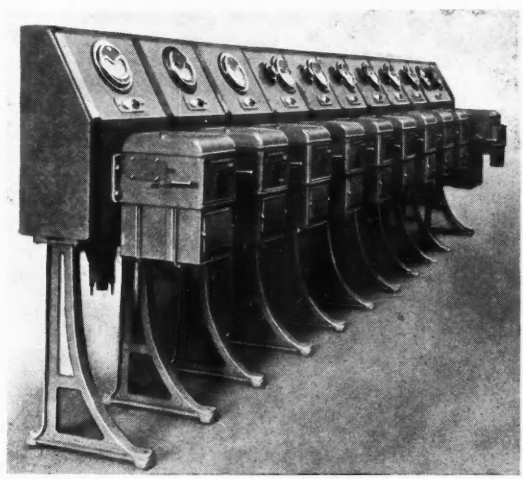

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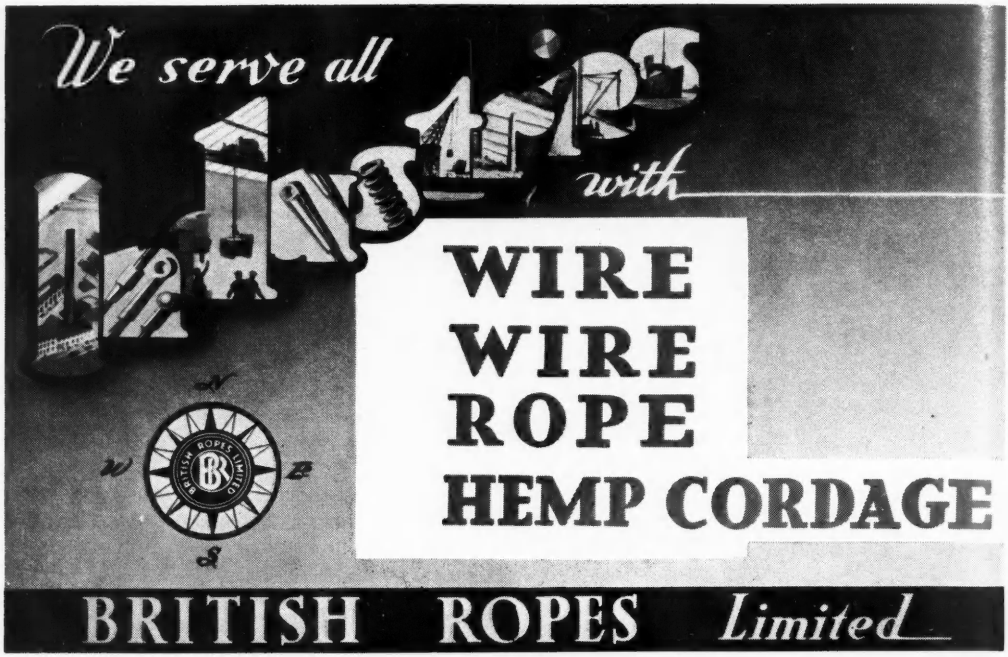

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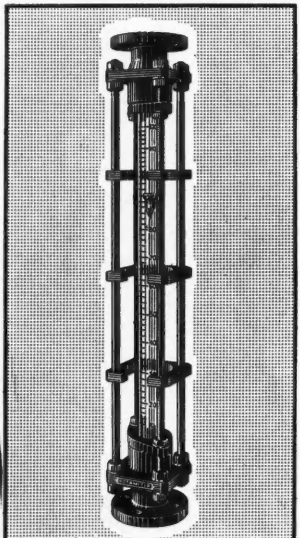

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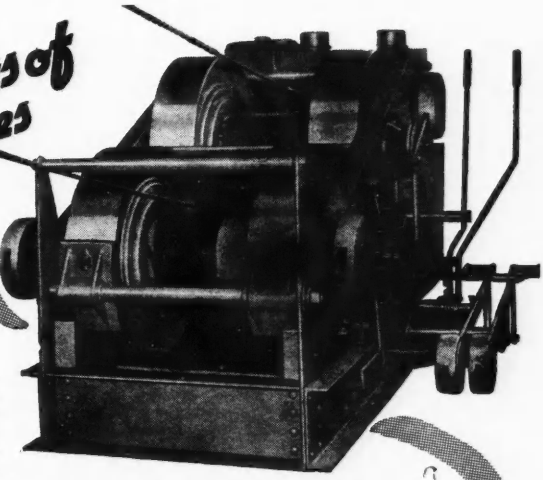

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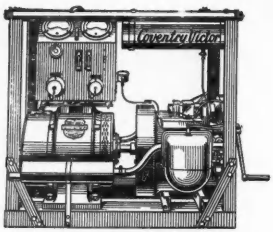

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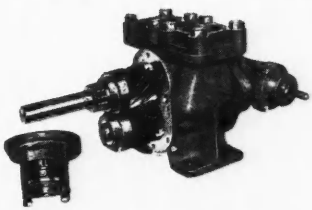

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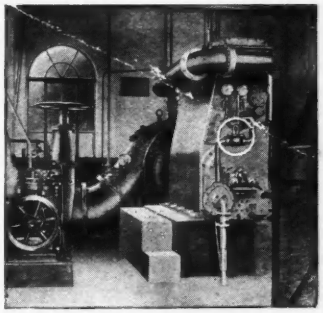

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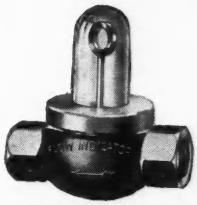

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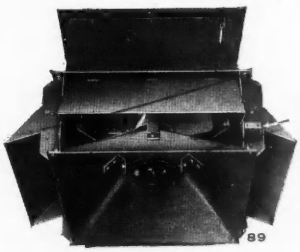

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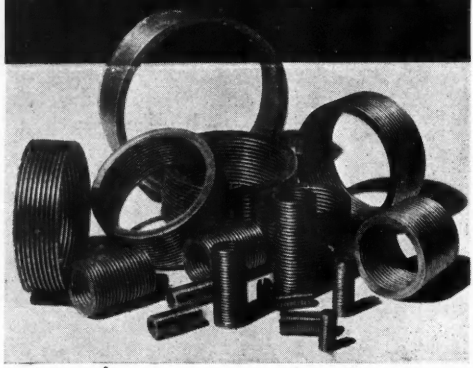

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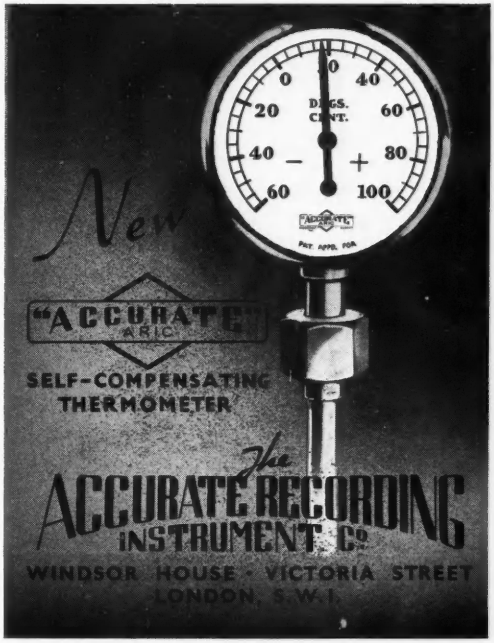

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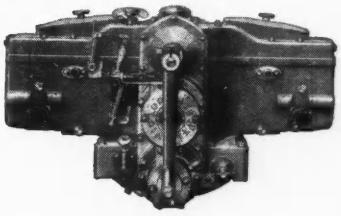

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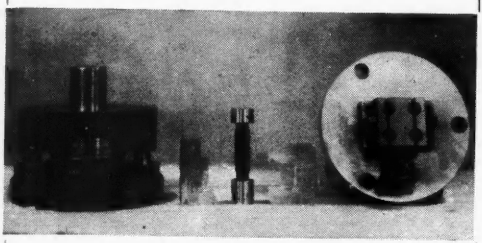

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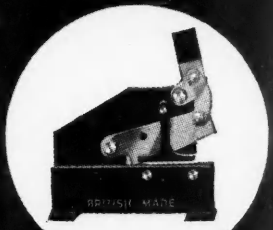

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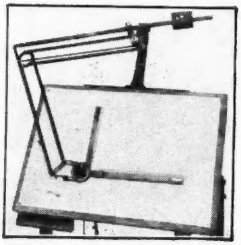

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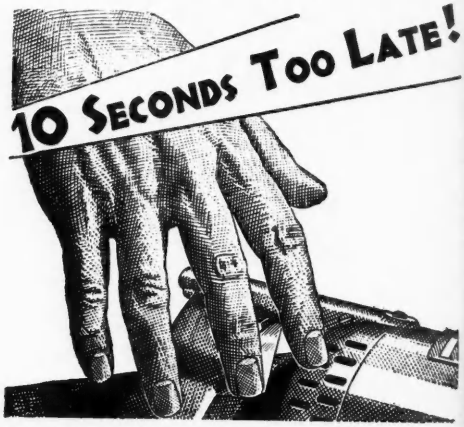

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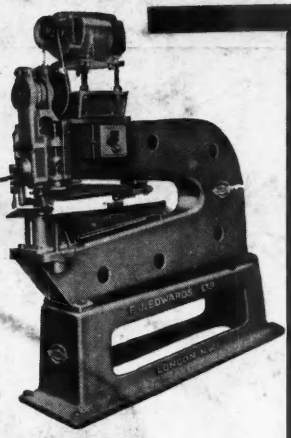

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